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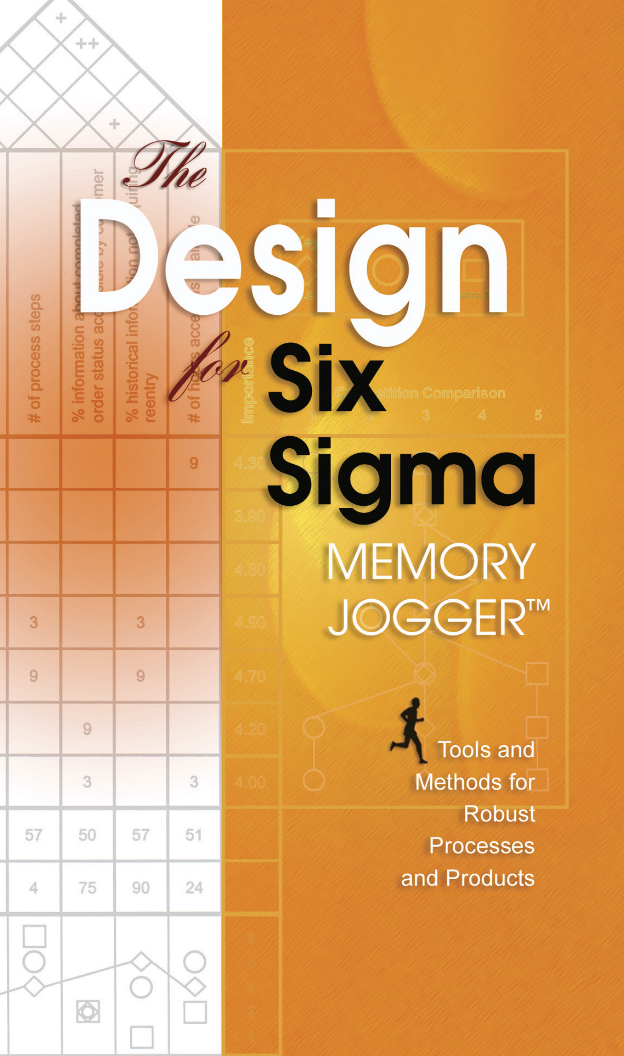
The Six Sigma Memory Jogger Library



The Design for Six Sigma

MEMORY JOGGER™

Tools and
Methods for
Robust
Processes
and Products

The Design *for* Six Sigma

MEMORY JOGGER™

Tools and
Methods for
Robust
Processes
and Products

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First Edition

GOAL/QPC

The Design for Six Sigma Memory Jogger™

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Printed in the United States of America
First Edition 10 9 8 7 6 5 4 3 2 1

ISBN 1-57681-047-X

Acknowledgments

Many thanks to all who offered encouragement and suggestions for this book and who gave us permission to use their examples and charts. In the truest sense, this has been a team effort.

Special thanks to Patricia Klossner and her team at Oriel, Incorporated who generously shared their time, knowledge, and experience, and to Larry Smith of Ford Motor Company who challenged us to create a book that meets the needs of both manufacturing and nonmanufacturing readers.

Thanks to the following reviewers whose suggestions helped to ensure that the finished book would meet their needs and expectations:

James Bossert, *Bank of America*; Kristi Spittler-Brown, *Wal-Mart Stores, Incorporated*; Michael S. Englund, *Honeywell, Incorporated*; Bruce K. Jankowski, *United States Surgical, Division of Tyco Healthcare Group LP;* Ian Osborn, *Maytag Corporation*; Jay P. Patel, *Quality & Productivity Solutions, Inc.*; Mary Beth Soloy, *Ford Motor Company;* David Speer, *Maytag Corporation*; Roger Stemen, *Raytheon Company.*

Foreword

At GOAL/QPC, we believe that Six Sigma is redefining the world of work and that organizations will need to incorporate the various Six Sigma methodologies into their training and education programs for current and future employess. Our main objective in developing *The Design for Six Sigma Memory Jogger™* is to provide a quick reference guide for people who are tasked with designing (or redesigning) processes, products, and services at six sigma levels of performance and to enable them to perform that work well. We are assuming that the users of this book will be experienced in the basics of Six Sigma, thus allowing us to concentrate our resources on the DMADV (Define, Measure, Analyze, Design, and Verify) steps of the Design for Six Sigma process.

Our goal, in creating this book, is to:

- Provide a clear roadmap that champions, project leaders, and project team members can follow from project initiation to closeout.
- Create a means for all parties involved in design activities to know where they are at any given point in the evolution of the project.
- Provide resources for further study and greater proficiency in tools and methods that, due to space limitations, could not be covered in greater detail in this book.

We hope that this and our other Six Sigma products will help to provide the information that your employees need to successfully meet the demands of their customers and stakeholders.

Bob Page
Director of New Product Development
GOAL/QPC

Table of Contents

How to Use this Book

The Design for Six Sigma Memory Jogger™ is designed to be a learning and performance support resource that will help all members of your team understand the sequence of activities in the DMADV process and learn how to perform each step and substep in the process.

To achieve these objectives and help you understand how all of this information fits together, we have created a number of features for this book, including:

- A flowchart and unique numbering system for the major DMADV process steps and substeps. (The complete flowchart is shown in The DMADV Methodology chapter, and sections of the flowchart are shown again as each major step is introduced.)
- A matrix that describes the major steps, the tools used to execute the steps, and the major outputs of each step. (The matrix is also included as part of The DMADV Methodology chapter.)

The individual chapters of the book explain each of the DMADV process steps in detail. The tools you will use to complete each step or substep can be identified by a toolbox icon at the beginning of each tool section, and are set off from the text by a blue background, to make them easier to locate. (Tools that are "nested" within other tool sections are set off on a white background.)

In addition, the Appendix to this book includes:

- A resource section with text and web-based resources for many of the highly detailed, industry-specific tools that are, unfortunately, beyond the scope of this book.
- A sigma conversion chart, for quick reference.
- A section on Storyboards, for convenience.

We hope you find this information useful on your journey to excellence!

Six Sigma Overview

What is Six Sigma?

Sigma is a statistical concept that represents the amount of variation present in a process relative to customer requirements or specifications. The higher the sigma level, the better the process is performing relative to customer requirements.

Too much variation	Hard to produce output within customer requirements (specifications)	Low sigma values (0–2)
Moderate variation	Most output meets customer requirements	Middle sigma values (2–4.5)
Very little variation	Virtually all output meets customer requirements (less than 4 defects per million opportunities)	High sigma values (4.5–6)

To increase the sigma level of a process, you must decrease the amount of variation and make sure that the process is targeted appropriately. Decreased variation provides:

- Greater predictability in the process.
- Less waste and rework, which lowers costs.
- Products and services that perform better and last longer.
- Happier customers who value you as a supplier.

Estimates place the quality levels of key processes in successful businesses today within the three- to four-sigma range. But an entire world operating at a four-sigma level would incur:

- At least 20,000 wrong drug prescriptions dispensed per year.
- Ninety-six crashes per 100,000 airline flights.
- Unsafe drinking water for almost one hour each month.
- No telephone service or television transmission for nearly ten minutes each week.

However, when a process operates at a *six-sigma* level, the variation is so small that the resulting products and services are 99.9997% defect free. A world operating at a six-sigma level would be much safer, with far fewer errors than the ones listed above.

In addition to being a statistical measure of variation, the term *Six Sigma* also refers to a business philosophy that says an organization is committed to understanding and providing what its customers need, by analyzing and improving its business processes to meet those needs. The organization has set a level of six sigma (no more than 3.4 defects per million opportunities [DPMO]) as a quality goal for the products and services it provides to its customers.

Note: *Six Sigma* is commonly denoted in several different ways—as *6σ*, *6 Sigma*, or *6s*. In this book, we will use the generic terms *sigma* or *process sigma* to refer to the current capability of a process (i.e., how well the process is performing relative to customer specifications).

Why should I use Six Sigma?

The many benefits of pursuing Six Sigma and using the accompanying methods include:

- Having a measurable way to track performance improvements.
- Focusing your attention on process management at all organizational levels.
- Improving your customer relationships by addressing defects.
- Improving the efficiency and effectiveness of your processes by aligning them with your customers' needs.
- Developing new processes, products, and services that meet critical customer requirements upon initial offering.

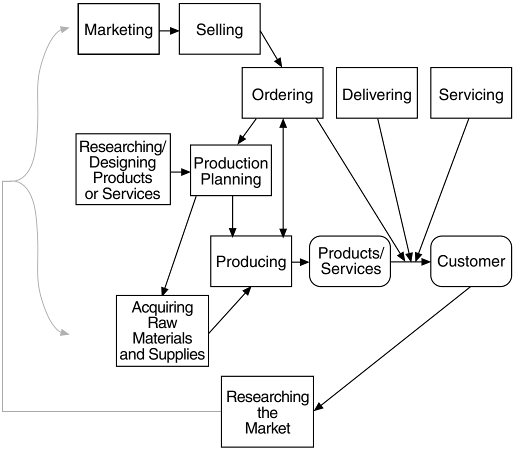
Two essential elements are implied in the definition of Six Sigma:

1. Understanding your organization's work from a *process viewpoint*, and
2. Clearly defining *customer requirements*

Process Viewpoint

To make changes that last, you must see your organization's work as the result of a series of interactive functions, operations, and methods called systems or processes. A process is a series of steps or tasks that converts an input into an output. Making an engine block, going on a sales call, filling a vacant position, or admitting a patient are all examples of processes. Processes apply to all work, whether repetitive in nature or "one-of-a-kind."

An Organization's Systems and Processes



Note: "Researching the Market" will provide customer feedback that can impact any part of the system or process.

In this diagram, the rectangular boxes represent the core processes. Linked together, they illustrate the highest-level process view in the organization. These processes interact to provide products and services to the customer.

To improve the quality of products and services (i.e., increase the sigma level), you must improve the systems and processes involved.

Customer Requirements

Customer requirements in Six Sigma are generally referred to as Critical to Quality (CTQ) characteristics. CTQs are those features of your product or service that are critical from the perspective of your customers.

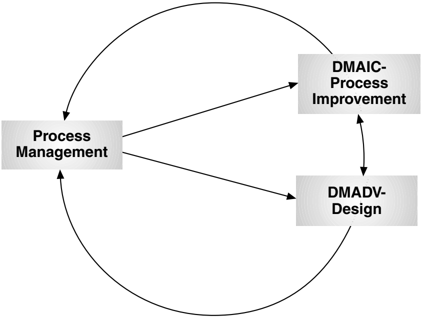
A CTQ should have:

- A quality characteristic that specifies how the product or service will meet the customer need.
- A quantitative measure for the performance of the quality characteristic.
- A target value that represents the desired level of performance that the characteristic should meet.
- Specification limits that define the performance limits that customers will tolerate.

Six Sigma methodologies

To achieve Six Sigma, a business must excel at managing existing processes (process management), improving existing processes (DMAIC), and designing new processes, products, and services (DMADV). Linking these three methodologies proves to be the most effective way for an organization to achieve its Six Sigma goals.

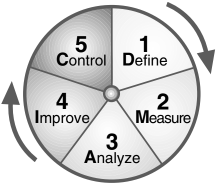
Linked Six Sigma Methodologies



Ongoing process management includes the *monitoring and control of an organization's processes*. Process management is both a source for new improvement and design projects, and the system that supports and maintains the projects' solutions. (This system is needed to sustain and improve a new design once it is fully implemented.)

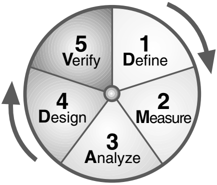
The Define-Measure-Analyze-Improve-Control (DMAIC) improvement process is used to *incrementally improve existing processes*. Improving an organization's processes will result in improved products and services.

DMAIC



The Define-Measure-Analyze-Design-Verify (DMADV) design process is used when a *new* process, product, or service is needed, or when an existing process, product, or service *requires such significant change* that an improvement process is inadequate.

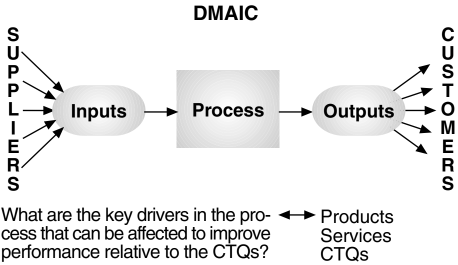
DMADV

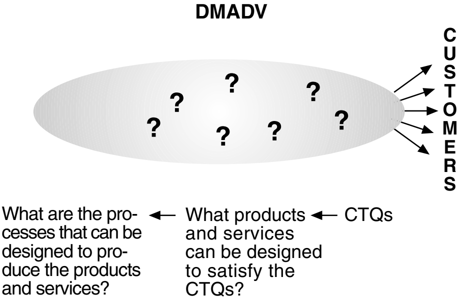


Both the DMAIC and the DMADV methodologies rely on a process viewpoint and an understanding of customer requirements.

Because *DMAIC* improves what currently exists, the Voice of the Customer work (i.e., the customer needs and perceptions) in DMAIC usually focuses on understanding the reasons the process, product, or service cannot consistently meet a key customer requirement. *DMADV*, on the other hand, usually involves substantially more work obtaining and analyzing the Voice of the Customer so that the process, product, or service is designed to meet multiple customer requirements from the outset.

DMAIC and DMADV Methodologies





Although some of the DMAIC and DMADV methodology steps have similar names, there are distinct differences in the purpose of the steps and in the tools used.

DMAIC vs. DMADV

DMAIC	DMADV
Define the project: • Develop a clear definition of the project. • Collect background information on the current process and your customers' needs and requirements.	**Define** the project: • Develop a clear definition of the project. • Develop organizational change plans, risk management plans, and project plans.
Measure the current situation: • Gather information on the current situation to provide a clearer focus for your improvement effort.	**Measure** customer requirements: • Collect the Voice of the Customer (VOC) data. • Translate the VOC into design requirements (CTQs). • Identify the most important CTQs. • Develop a phased approach if necessary.
Analyze to identify causes: • Identify the root causes of defects. • Confirm them with data.	**Analyze** concepts: • Generate, evaluate, and select the concept that best meets the CTQs within budget and resource restraints.
Improve: • Develop, test, and implement solutions that address the root causes. • Use data to evaluate results for the solutions and the plans used to carry them out.	**Design:** • Develop the high-level and detailed design. • Test the design components. • Prepare for pilot and full-scale deployment.

Continued on next page

DMAIC	DMADV
Control: • Maintain the gains that you have achieved by standardizing your work methods or processes. • Anticipate future improvements and make plans to preserve the lessons learned from this improvement effort.	**Verify** design performance: • Conduct the pilot, and stress-test and debug the prototype. • Implement the design. • Transition responsibility to the appropriate people in the organization. • Close the team.

Why should I use DMADV?

There are reasons why an organization would want to apply DMADV instead of DMAIC:

- To design processes, products, and services that do not currently exist
- To improve an existing process, product, or service if:
  - It is not designed for current capacity
  - It fails to meet multiple customer requirements
  - There are multiple fundamentally different versions in use
  - The organization cannot improve the process, product, or service using the existing technology, as evidenced by repeated unsuccessful improvement attempts

People tend to differentiate between product and service designs. However, black-and-white distinctions between products and services are not meaningful in practice. The output of most industries is a mixture of both. For example, a service industry such as banking has associated physical products (e.g., an ATM) whose quality is an integral part of the service experience.

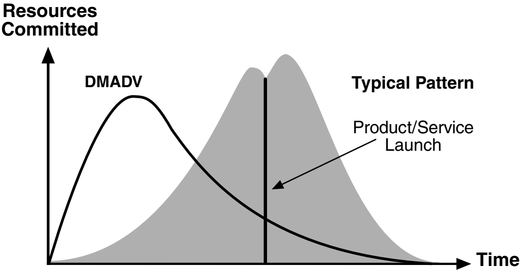
Customers do not make distinctions between the product and service aspects of an organization; customers view the outputs of a company as a package, and the total performance of the elements of the package determines the degree of customer satisfaction. By focusing explicitly and systematically on customer needs, the DMADV methodology supports the design of all of the elements that are needed to delight customers.

DMADV allows an organization to *refocus on the customer requirements*, ensuring greater accuracy and reduced variation about the target in a way that can provide dramatic results and high sigma levels from the outset.

It is generally accepted that the DMAIC methodology can shift a sigma level from 3 sigma to about 5.0–5.5 sigma. At that point, the rate of return on effort diminishes considerably. For this reason, continued use of the DMAIC methodology may be inadequate. To achieve higher sigma performance, you must *redesign* the process, product, or service so that the *design itself* will ensure the capability of achieving a higher level of performance.

DMADV does require a significant time and effort investment up front, but in the long term, it is much more cost-efficient because you do not incur the costs to correct problems after you introduce a new process, product, or service. The typical post-release activity represents fixes and redesigns that are necessary to repair the original design as it moves into full implementation. The DMADV methodology minimizes this crisis activity by delivering processes, products, and services that are more likely to meet customer and business requirements from the initial launch.

DMADV Reduces Typical Post-Release Activities



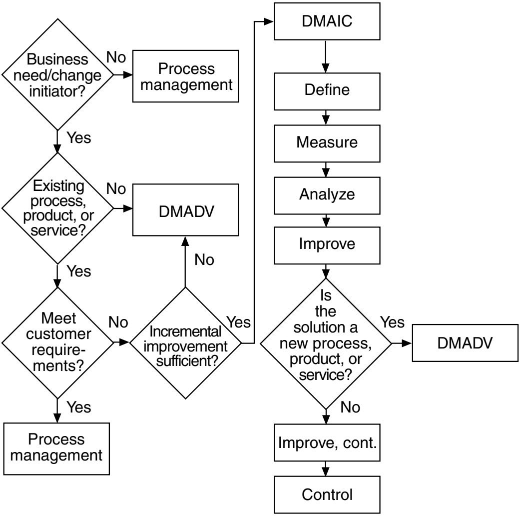
Projects that use the DMADV methodology use fewer resources and use them up front. This can be challenging to many organizations because key resources are requested when there is no crisis and these organizations are accustomed to doing the first stages of projects with less investment.

Deciding between DMAIC and DMADV projects

Regardless of whether an organization begins with DMAIC or with DMADV, project generation and selection are critical steps *prior* to initiating the improvement or design cycles.

Use the Flowchart on the next page when initiating projects to determine whether the project should follow a DMAIC or a DMADV path.

Should I Use DMAIC or DMADV?

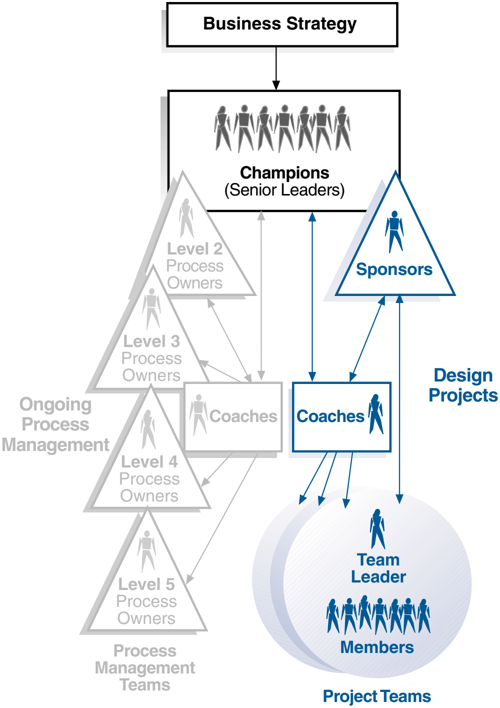


What are the roles and responsibilities associated with a DMADV project?

Each DMADV project requires a coordinated effort among many people.

Senior business leaders or champions identify objectives for the organization's processes, products, and services based on the organization's strategic plans. Depending on how well the current processes, products, and services perform, champions identify which existing processes, products, or services need improvement, and which new processes, products, or services need to be designed.

Six Sigma Roles



There are five major roles in a DMADV project. Their primary responsibilities are explained on the following pages.

Champions

- Select key areas for change
- Select design projects that are linked to the strategic direction and business needs
- Identify the design team sponsor
- Identify the process owner and ensure his/her appropriate involvement in the project
- Manage the project "pipeline"
- Approve charters
- Coordinate/integrate projects
- Review progress
- Approve recommended solutions and funding
- Ensure that management systems can maintain the gains across the business
- Recognize and communicate efforts

Project Sponsor

- Selects the coach and team leader
- Drafts the team charter
- Provides needed resources
- Selects team members with the team leader
- Collaborates with the team leader to orient the team to the project
- Reviews team progress frequently
- Provides guidance, direction, and support
- Intervenes to remove barriers to success
- Monitors other initiatives for overlap/conflicts
- Helps transition responsibility from the team to the organization during implementation and ongoing monitoring

- Informs the champions' group and others of progress/learnings
- Ensures that recommended changes are implemented
- Ensures that project results are quantified and documented
- Ensures continued monitoring of key processes, measures, and solutions
- Preserves and uses the lessons learned
- Celebrates the team's accomplishments

Coach (often referred to as the Master Black Belt or Quality Advisor)

- Develops team leaders
- Facilitates team success
- Provides design and statistical/technical expertise
- Coaches sponsors and process owners

Team Leader (often referred to as the Black Belt)

- Is responsible for the project's progress and planning the team's work
- Communicates to the project sponsor and management team
- Develops, updates, and manages all project plans
- Does the project work, in conjunction with team members

Team Member

- Supplies necessary technical expertise and does the project work
- Works collaboratively with others to develop, test, and implement the design
- Leads sub-teams (as necessary) during some phases of the design

Sources for DMADV Projects

There are many potential sources for DMADV projects. These include, but are not limited to:

- New opportunities created by a research or development breakthrough.
- A need to respond to a competitor's move.
- A desire to leapfrog the competition and gain competitive advantage.
- The implementation of regulatory/certification requirements.
- A need to meet new customer requirements.

There are basically two ways to initiate DMADV projects. The first is to have the business strategy initiate projects directly. For example, design efforts can result from identifying new markets or market segments to target, deciding to offer new products or services to existing customers to maintain their loyalty, or reframing the business purpose (e.g., moving from a "cash register" company to a "business solutions" company).

A second source of DMADV projects is through improvement projects that, after analyzing the underlying cause/effect relationships responsible for customer unhappiness, demonstrate that improving existing processes, products, or services will not meet customer requirements. A new design is needed.

Regardless of how it is initiated, a DMADV project should begin with information about how it is expected to contribute to the business strategy and the market or customer requirements it is intended to address.

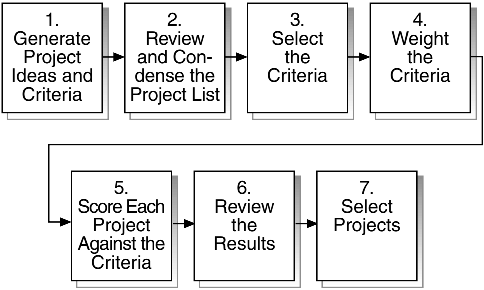
Choosing a collection of projects is quite similar to managing an investment portfolio. In both cases you need to:

- Balance solid, smaller payback with riskier high returns.
- Balance short-term and long-term gain.
- Address the diversity of strategic issues.

How do I select DMADV projects?

Select projects that will have the greatest impact on the business strategy, key performance indicators, and critical customer requirements. Then communicate the project in a way that clearly describes the link between the project and the strategic priorities of the company, and that describes how the benefits of the project will be measured.

Project Selection Process



To select DMADV projects:

1. **Generate project ideas and criteria based on the business issues.**
   - Consider:
     - The organization's strategic direction.
     - Customer information.
     - Competitive, industry, and benchmarking trends and data.
     - Current management dashboards and other measures.
     - Current bottlenecks to success.
     - Other related data from the business, employees, and marketplace. To uncover this data, ask:
       a) What new products, services, or other capabilities can we create to provide increased value to our customers and shareholders?
       b) Which processes are the most expensive? Which are the most cumbersome?
       c) What barriers exist that prevent us from increasing customer satisfaction?
       d) What new needs are on the horizon for our customers? How can we better anticipate those needs?
       e) What concerns or ideas have employees raised?
2. **Review and combine the project list that you develop with any existing project lists.**
3. **Select criteria to use in further condensing the project list.**
   - Consider:
     - Clear links to the business strategy.
     - The resources available to allocate.

  - The potential high impact to profitability through increased revenues and/or reduced costs.
  - The availability of customer data or the relative ease to collect this data.
  - The potential for the project to significantly increase process performance.
  - The ability of the project sponsor to commit time and resources.
  - The funding available for solutions.
  - A manageable time frame (generally, 6–12 months; longer design projects can be handled in six-month phases).

4. **Weight the criteria.**
5. **Score each potential project against the criteria.**
6. **Review the results to ensure that they make sense.**
   - Identify and reconcile any inconsistencies.
7. **Select the initial projects.**

What do I need for a successful DMADV program?

Your DMADV initiative will only be successful if your organization's culture supports its continued and consistent use. To accomplish this, your organization should:

- Have management lead your improvement efforts.
- Actively support a focus on delighting your customers.
- Provide the DMADV project team with access to experts who can offer ongoing guidance and coaching.

- Encourage open discussion about defects. (People should not be afraid to point out that something is wrong. The airline industry, for instance, studies crashes and "near-misses" to improve safety.)
- Value and use the data you gather.
- Help employees work effectively by providing a team-based, cooperative environment.

The DMADV Methodology

What is the DMADV methodology?

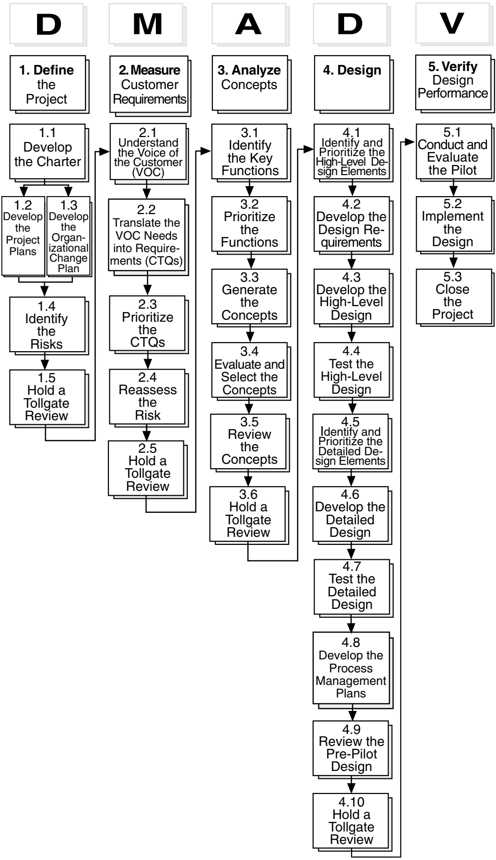
DMADV is a five-step method for designing new processes, products, or services, or completely redesigning ones that already exist. The flowchart on the next page shows the five steps and their associated substeps. (Each step is explained in greater detail in subsequent chapters of this book.)

> ***Tip*** Although the process appears linear and there is a specific order to the work (e.g., you gather information on customer needs before generating concepts, and you work at the concept level before attempting to design the details), there are also a lot of recurring actions within the design process. For example, you will start to gather customer requirements as part of the Measure step, but will continue to deepen your understanding of customer requirements throughout the Analyze and Design steps.

Note: In this book, the steps and substeps of the DMADV process are sequentially numbered to serve as a navigational aid. As you read this book, use this numbering system and the linear DMADV methodology flowchart to quickly orient yourself to your current position in the process.

Each step of the DMADV method uses specific tools that generate specific outputs, as detailed in the chart at the end of this chapter.

The DMADV Methodology



Steps	Tools	Outputs
1. **Define** the project: • Develop a clear definition of the project. • Develop organizational change plans, risk management plans, and project plans.	• Market analysis tools: - Market forecasting tools - Customer value analysis - Technology forecasting and visioning - Competitor analysis • Process analysis tools: - Control charts - Pareto charts • Traditional project planning tools: - Work breakdown structures - PERT charts - Gantt charts - Activity network diagrams • DMADV-specific tools: - Project charter - In-scope/out-of-scope tool - Organizational change plan	• Project charter • Project plan • Organizational change plan • Risk management plan • Tollgate review and Storyboard presentation
2. **Measure** customer requirements: • Collect the Voice of the Customer (VOC) data. • Translate the VOC into design requirements (CTQs). • Identify the most important CTQs. • Revise the risk management plan. • If necessary, develop a multistage project plan.	• Customer segmentation tree • Data collection plan • Customer research tools: - Interviews - Contextual inquiry - Focus groups - Surveys • VOC table • Affinity diagrams • Kano model • Performance benchmarking • Quality function deployment (QFD) matrix • CTQ risk matrix • Multistage plan • Tollgate review form	• Prioritized CTQs • Updated risk management plan and multistage project plan, if appropriate • Tollgate review and updated Storyboard

Steps	Tools	Outputs
3. Analyze concepts: • Generate, evaluate, and select the concept that best meets the CTQs within budget and resource constraints.	• QFD matrix • Creativity tools: - Brainstorming/ Brainwriting - Analogies - Assumption busting - Morphological box • Pugh matrix • Tollgate review forms	• Selected concept for further analysis and design • Tollgate review and updated Storyboard
4. Design: • Develop the high-level and detailed design. • Test the design components. • Prepare for pilot and full-scale deployment.	• QFD matrix • Simulation • Prototyping • Design scorecard • FMEA/EMEA • Planning tools • Process management chart • Tollgate review forms	• Tested and approved high-level design • Tested and approved detailed design • Detailed, updated risk assessment • Plans for conducting the pilot • Completed design reviews and approvals • Tollgate review and updated Storyboard
5. Verify design performance: • Conduct the pilot and stress-test and debug the prototype. • Implement the design. • Transition responsibility to the appropriate people in the organization. • Close the team.	• Planning tools • Data analysis tools: - Control charts - Pareto charts • Standardization tools: - Flowcharts - Checklists - Process management charts	• Working prototype with documentation • Plans for full implementation • Control plans to help process owners measure, monitor, and maintain process capability • Transition of ownership to operations • Completed project documentation • Project closure • Final tollgate review and updated Storyboard

Define
Customer Requirements

Why do it?

To develop a clear definition of the project that includes project plans, risk management plans, and organizational change plans. Projects that do not define their objectives, assign roles and responsibilities, and develop a project plan at this point in time often return to the Define step at a later date. This causes delays, disillusions teams, and generally threatens a project's viability.

Tools used in this step:

- Market analysis tools:
  - Market forecasting tools
  - Customer value analysis
  - Technology forecasting and visioning
  - Competitor analysis
- Process analysis tools:
  - Control charts
  - Pareto charts
- Traditional project planning tools:
  - Work breakdown structures
  - PERT charts
  - Gantt charts
  - Activity Network Diagrams

- DMADV-specific tools:
  - The project charter
  - The In-Scope/Out-of-Scope Tool
  - The organizational change plan
  - Risk management plans
  - Tollgate Review Forms

Note: Market analysis tools are beyond the scope of this book. Process analysis tools are explained in *The Six Sigma Memory Jogger™ II*. Traditional project planning tools are highlighted here and can be referenced in more detail in *The Six Sigma Memory Jogger™ II* and the *Project Management Memory Jogger™*.

Outputs of this step:

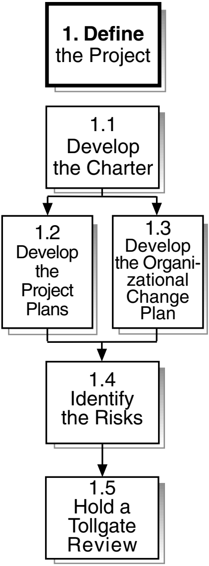
- A project charter
- A project plan
- An organizational change plan
- A risk management plan
- A tollgate review and Storyboard presentation

Key questions answered in this step:

- What are the strategic drivers for the project?
- What is the problem or opportunity we are trying to address?
- Why is improvement or the Plan-Do-Check-Act (PDCA) Cycle not adequate?
- What is the scope of the project?
- What is the project timeline and completion date?
- What team resources are needed?

- What are the major risks associated with the project? When and how will we address those risks?
- How can we make sure the organization embraces and supports the changes resulting from the design?

How do I do it?



1.1 Develop the Charter

What is it?

The charter is an agreement between the champion team and your design team about what is expected of the project. The charter goes through several rounds of discussion as the project sponsor and the design team clarify uncertainties in definition and expectations. When the sponsor and the design team reach an agreement, the sponsor presents the charter to the champion team and facilitates communication between senior leadership and the design team.

Note: The charter will continue to evolve as the project unfolds and will need to be reviewed and updated periodically.

Why use it?

- To clarify what is expected of your design team and the design project before proceeding further
- To keep your team focused and aligned with organizational priorities
- To transfer the project from the champion team and sponsor(s) to the design team

How do I do it?

1. Define the problem statement.

- Describe the current situation and what is triggering the need for the design. Also describe the problems or challenges that internal and external customers experience, by addressing:

  - What is wrong or not working?
  - When and where do problems occur?
  - How extensive are the problems?
  - What is the impact on our customers, our business, and our employees?
  - What will be the impact of changes in the market or business?

2. Create an opportunity statement.

- Describe the market opportunity that the new process, product, or service would address and the potential financial opportunity to which it could lead. Ask:
  - Who are the intended customers?
  - If we address this problem or issue, what benefit or value is added?
  - Will current customers increase their purchases?
  - Will addressing the problem or issue allow us to expand existing market segments or acquire new segments?
  - Will new customers begin to purchase from us?
  - Will customers purchase higher-margin products or services?
  - If we decrease costs, can we gain market share by passing the cost savings on to customers?

Tip If the DMADV project is focused on a new market opportunity instead of a problem to be fixed, then the opportunity statement becomes a more important part of the charter than the problem statement.

3. Define the importance of the project.

- Address the questions:
  - Why do this project now?
  - How does the project connect to the organization's short-term and long-term business strategies and/or objectives?
  - What is the larger picture that this project is part of?
  - How does this project contribute to the mission of the organization?

4. List the expectations/deliverables.

- Define the gap that the design will fill when completed. Define what you need to design, but do not specifically describe the process, product, or service that you will develop. Ask:
  - What will be the outcome of the design project?
  - What are the key elements (e.g., processes, information systems, technologies, people) that the design needs to address?
  - How will we know when the design is complete?
  - How will we know that the design is successful (e.g., by measuring target defect rates, margin improvements, customer satisfaction targets, or revenue growth)?

5. Determine the project scope.

- Determine what aspects of the process, product, or service the design will address, and ask:
  - What are the boundaries (starting and ending points) of the initiative?
  - What parts of the business are included?
  - What parts of the business are not included?

  - What, if anything, is outside of the team's boundaries?
  - What constraints (e.g.,no external resources, use existing technologies, etc.) do we need to work within?
  - What are the nonnegotiables (e.g., time to market, etc.)?

Tip When drafting the charter, define the scope as well as possible given the information available at that point in the project. You will refine the scope in subsequent steps.

- Use the In-Scope/Out-of-Scope Tool to help you define the boundaries of the project.

What is it?

The In-Scope/Out-of-Scope Tool is a graphical method that clarifies the project's scope.

Why use it?

To help the team clarify which elements are within the boundaries of the project.

How do I do it?

1. Brainstorm the elements of the project.

- Write each element on a separate Post-it® Note.

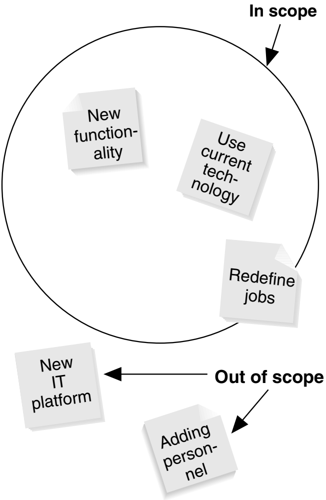
2. Draw a circle on a flipchart to indicate the project's boundaries.

3. Place the notes on the flipchart.

- Put the note inside the circle if the element is within the project's scope.
- Put the note outside the circle if the element is not within the project's scope.
- Put the note on the boundary of the circle if you are not sure if the element is within or outside the project's scope. Discuss any such items with the project sponsor.

4. Review the chart with the sponsor.

An In-Scope/Out-of-Scope Tool Example



6. Create a project schedule.

- Include key milestones and the target dates for the completion of major steps in the project. Ask:
  - What are the critical milestones for the project?
  - What deadlines must we meet and why?
  - What reviews should we schedule and when?
  - What other business constraints must we take into account in scheduling the project?
- Focus on the key dates when deliverables are expected from the team. These dates will be estimates when you initially charter the project and may change when you learn more as the project progresses. Update the key dates and discuss these dates during project reviews.

Note: Design projects are usually very complex and often involve several teams working concurrently on different parts of the design during the latter steps in the process. Therefore, tracking progress against the plan for these projects usually requires excellent project management skills and project management software.

7. List the team resources.

- Identify the resources available to the team for specific tasks or specific periods of time. Answer:
  - Who are the team members? Who is the team leader? Sponsor(s)? Key stakeholders? Other subject matter experts? What are their responsibilities?
  - Which business functions or areas of expertise do we need? At what stage will we need them?
  - How much time can each person devote to this project? How will their regular work be handled while they are on this project?

  - What is the project structure? Who is accountable to whom and for what?
  - How is the project linked to line management? What review structures are in place?

- Choose team leaders who have excellent project management skills, strong data analysis skills, knowledge of and experience in leading process improvements, and an ability to achieve results.
- Because design projects are often complex, cross-functional (sometimes cross-business), and critical to achieving business strategies, select sponsors who possess the skills and authority to mobilize resources, address barriers and conflicts, guide the team, and champion the project.
- When chartering the team, ensure that the initial core team represents all of the functions and areas of expertise that the project needs during the initial stages. After you choose a design concept, you may need to change the team's composition and add people to the design team. Make sure the team leader and coach are well-trained and experienced.

Tip Ensuring that design teams have all key functions and skills represented on the core team is critical to their success. Check the team composition for cross-functional representation, key skill areas, and experience levels. (For example, a team may need members from engineering, information technology, risk management, legal, finance, marketing, sales, and distribution departments.) In addition to including key skills on the team, create a team that blends both experience and new ideas, and include members who represent diverse perspectives. Review team membership at the end of each phase in the design process; add or change members as needed for the work in the upcoming phase.

Tip Discuss who will be responsible for key tasks and how the team expects to work together before the project gets underway. This process, called role contracting, sets clear expectations and prevents misunderstandings and conflicts.

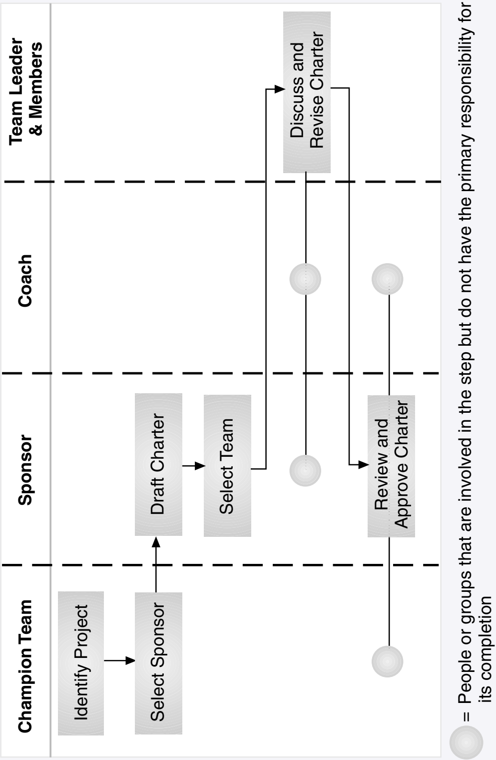
Use the following questions to help reach agreements about how the sponsor, team leader, coach, and team will work together:

- When should the team go to the sponsor for approval?
- When should the team and sponsor review progress? What is the coach's role in the reviews? Who has which responsibilities for the reviews?
- What topics should the team leader and sponsor discuss between reviews? Who should structure these meetings?
- How should the coach work with the sponsor? With the team leader? With the team?

Be sure to document these conversations to ensure clarity throughout the project.

A champion group usually selects the design projects and a project sponsor oversees the project. The project sponsor selects the team leader and drafts an initial charter, perhaps with input from the team leader. The team then discusses the charter, adding data, clarifying the charter elements, and noting any necessary revisions given their understanding of the project, its scope, and its customers. The team submits the revised charter to the sponsor for further discussion and approval.

Responsibilities When Developing a Charter



= People or groups that are involved in the step but do not have the primary responsibility for its completion

A Sample Project Charter for Defining a Process or Service

Problem Statement:

As customers become more mobile, they have a growing need to place orders at any time, from any place, and through any channel. Our current order placement facility is unable to meet this need.

Opportunity Statement:

Over 50% of customers have access to more than one ordering channel. Studies have shown that this is the case for our competitors' customers as well. Providing flexible, multichannel access allows us to delight our own customers and gives us a significant competitive advantage over the current capabilities of our competitors.

Importance:

Multichannel ordering is currently gaining significant attention in the business world, and is the topic of many well-attended seminars and conferences. Speed of entry into this area will be a critical determinant of competitive advantage.

Expectations/Deliverables:

Design and build the processes, systems, and human resources needed to support flexible, multichannel ordering.

Scope:

The processes to be developed start when a customer places an order. The end point is when the order is transmitted into the production system and the customer receives confirmation. Orders are limited to domestic finished products and do not include direct orders for raw materials.

Project Schedule:

The overall project needs to be completed no later than 8/30.

- Define step by 2/15
- Measure step by 4/1
- Analyze step by 5/1
- Design step by 7/1
- Verify step by 8/25

Team Resources:

Julie	*Sponsor*	Eric	*Coach*
Beth	*Team Leader*	Pete	*Information Technology*
Sara	*Sales*		
Jack	*Operations*	Jan	*Marketing*
Betty	*Finance*	Luis	*Production*

Tip Be sure to spend sufficient time discussing and clarifying the charter elements to ensure that all team members, sponsors, and stakeholders understand the project's focus and scope. The initial charter should utilize whatever relevant data is available at the time. Remember that the charter is a living document that you will revise as you gather and analyze new data as the project progresses.

1.1 Develop the Project Plan

What is it?

The project plan is a detailed description of the project schedule and milestones. The plan includes an organizational change plan, a risk management plan, and a review schedule.

Why use it?

- To organize your team's daily activities (at the most detailed level)
- To help management review schedules and deadlines (at a task summary level)
- To allow an executive review of progress across projects (at the milestone level)

How do I do it?

1. Integrate DMADV with your organization's related established processes.

- Design projects often need to be integrated with other standard organizational processes (e.g., an existing product development or software development process). Spending time with others in the organization at the beginning of the project to integrate the project plan into those existing systems is usually well worth the effort because it may identify additional tasks that you will need to include in the project plan.

2. **Develop the project schedule.**

   a) Start with important milestones. Milestones represent important decision points. The completion of each step in the design process is usually one of the milestones.

   - Use the expertise of the entire team to define milestones. Ideally, you should have 10–15 milestones.

   b) Organize the milestones into a logical sequence.

   - Use tools such as Gantt charts, PERT charts, or Activity Network Diagrams to show the relationships between the milestones, define the critical path (i.e., the path of connected activities that shows the quickest possible implementation time), and build your project schedule.

   c) Develop a detailed task structure.

   - List the activities that must be completed in the project. Include:
     - Work tasks.
     - Coordination activities.
     - Communication activities.
     - Meetings.
     - Status reports and schedule reviews.
     - Design reviews.
     - Tollgate reviews.

   d) Establish the task relationships.

- Ask:
  - What inputs does this activity require and where do they come from?
  - Does this activity produce any outputs that are required in another activity?
  - What activities must be completed so that this activity can be completed?
  - Where or how are the outputs of this activity used?
  - Can any activity be completed independently of other activities?

Tip When thinking about the relationships between the tasks, identify which activities must be completed before other tasks can begin, and which tasks cannot start until other tasks have begun. Determine how long each task will take (actual work time) and over what period of time (elapsed time). Identify the resources for each task to enable people to coordinate their work schedules.

e) Identify the critical path.

- Use the expertise of the entire team to establish dates for milestones. To estimate the target date for each milestone:
  - Estimate the tasks needed to reach each milestone.
  - Estimate the actual work time required for each task.
  - Estimate the resources available for each task.
  - Take into account factors such as time off, overtime required, learning curves, meetings, and time for consensus building.
  - Understand the relationships between the tasks needed to accomplish each milestone.

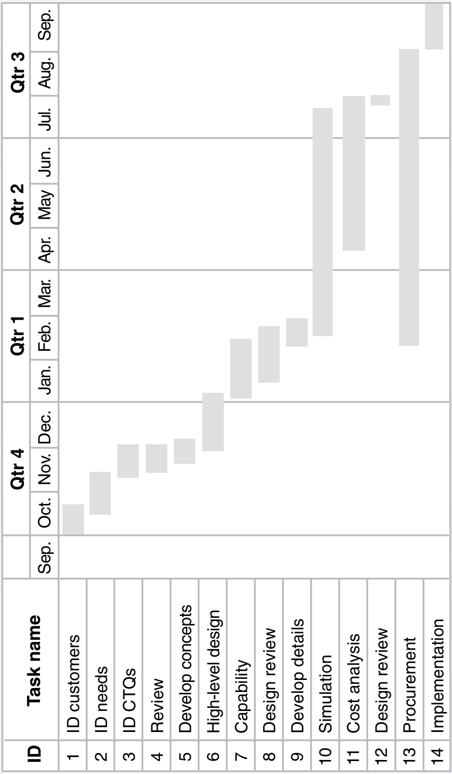
- Use this information to determine the total duration time for each task and the overall project timeline.

A Sample Critical Path Matrix

Activity	Prede-cessors		Early		Late		Total Slack
			Start	Finish	Start	Finish	
A. Reporting relationships determined and documented		5 Days	3/4	3/10	3/4	3/10	0
B. Detailed office layouts completed	A	5 Days	3/11	3/17	3/11	3/17	0
C. Equipment needs identified	B	15 Days	3/18	4/7	3/18	4/7	0
D. Equipment ordered and received	C	25 Days	4/8	5/12	4/8	5/12	0
E. Installation of telephone/fax lines complete	C	5 Days	4/8	4/14	4/22	4/28	10
F. Installation of computer network complete	E	10 Days	4/15	4/28	4/29	5/12	10
G. Furniture needs identified	B	5 Days	3/18	3/24	4/8	4/14	15
H. Furniture ordered and received	G	20 Days	3/25	4/21	4/15	5/12	15
I. Equipment moved and installed	D,F,H	5 Days	5/13	5/19	5/13	5/19	0
J. Personal items moved	I	5 Days	5/20	5/26	5/20	5/25	0

You can also use a Gantt chart to summarize the flow of tasks across a timeline.

A Sample Gantt Chart



Tip Design projects often have very complex task relationships because many concurrent activities occur simultaneously. Use a "rolling horizon" approach to develop detailed plans (i.e., create detailed plans for work to be done about four weeks out from the work currently being completed). The work that is further in the future can be left at a less-detailed level for now. Use a work breakdown structure (i.e., group the project tasks into a hierarchy that organizes and defines the total project work) to help you develop the task structure.

3. Develop project management controls.

- Identify the controls that protect the most vulnerable aspects of your project. Good project controls should:
  - Match the needs of the project.
  - Focus on a few key items.
  - Be reviewed and agreed upon by the team.
  - Be tested and understood before they are needed.

  Project controls ensure that planned events occur as planned, and unplanned events don't occur. All complex projects need project controls, but what the controls will focus on varies with the project. (For example, some projects may need safety and environmental controls while others need controls for work practices and ethical conduct.) The projects most in need of control mechanisms are those that involve a lot of people, over a long period of time, designing high reliability products or services.

- Be sure to match the controls to the project needs. Make them as simple and easy to use as possible. Make sure the benefits of the controls are understood so that everyone will support their use.

One example of a control mechanism is an issues board. An issues board lists the top 10–20 issues or problems associated with a project. Each issue is color-coded (green = "under control," yellow = "help needed," and red = "emergency"). The issues board is updated regularly (often daily) and also lists the person responsible for addressing the issue and the number of days the item has been on the list.

Category	Issue	Lead Person	Days Open
● Red	Need customer data from potential markets	Luis	15
● Green	Reschedule tollgate review	Jan	2
● Yellow	Get cost/benefit data from Chief Financial Officer	Beth	4

4. Control the project documentation.

- Develop a method for organizing your project documents. If your organization already has a document management system, use it for your design project.

Document control is critical to control and manage the design changes while the sub-teams work concurrently. Document control should include:

- A central storage area (with a backup) to ensure centralized document retention.
- A date of creation and a version number on each document.
- Documents in the storage area that are accessible, but not available for modification.

Because documents change many times during a project, version control is an important issue. Find an easy way for team members, sponsors, and stakeholders to locate the most current version of all documents. Develop methods to review proposed changes in the documentation and to make approved changes in all relevant related documents.

1.3 Develop the Organizational Change Plan

What is it?

An organizational change plan ensures that the organization is prepared to support the project. The plan includes various change readiness assessment maps and communication plans.

Why use it?

To ensure that resources will be available and willing to help when needed. The organizational change plan will show who the change will impact and when their support will be needed in the project cycle.

Change is difficult for many people because the "way things are" is comfortable and often is part of their identity. To help people let go of the way things are and become supporters of the change, be sure to:

- Communicate vividly why things must change (e.g., customer demands/dissatisfactions, competitive pressures, technology changes, etc.).
- Allow people to express their fears and concerns.
- Provide mechanisms to solicit opinions and concerns, dispel rumors, and address fears.

You may need to develop multiple layers in your change strategies because people undergoing change have different needs. Change strategies for some people will center on communication. For others, the strategy may involve them in some of the team's activities and include them in key design decisions and reviews.

How do I do it?

1. **Create an organizational change plan with three components:**
   - A *change readiness assessment* that determines how ready individuals and organizations are to accept and embrace change
   - A *change path visioning* component that shows the expected path of the change process and how driving forces (accelerators) and restraining forces (resistors) will influence the expected change path
   - A *change implementation and management* component that describes the strategies to create acceptable and sustainable change in the organization

Change readiness assessment

1. Create a critical constituencies map.

- This map helps you identify the extent to which the change will impact various groups in the organization.
  - a) List the groups that have a stake in the change (stakeholders) in the left-hand column of a matrix.
  - b) Determine the percentage of each group that will be affected by the change and record these percentages in the center column.

c) List the impact of the change (high, medium, or low) on the group in the right-hand column.

A Sample Critical Constituencies Map

Organization	Percent Affected	Change Impact
Sales	50%	High
Marketing	10%	High
Operations	75%	Low

Note: Even though the percentage of the organization affected by a change may be low, the impact on this small percentage may be high and therefore cannot be ignored.

2. Create a change readiness map.

- A change readiness map helps teams identify stakeholders' attitudes toward change. It quantifies the stakeholders' attitudes, articulates the reasons for resistance to the change, and identifies the advocates for change.

  a) List the stakeholders in the left-hand column of the matrix.

  b) Label three additional columns as "% early adopters," "% late adopters," and "% non-adopters" of the change. Label a fourth column "reasons for resistance."

  c) Determine the percentage of each group of stakeholders who will likely fit into each category and record these percentages in the appropriate cells.

  d) Identify the reasons why each group could be resistant to the change and record this information in the appropriate cells.

A Sample Change Readiness Map

Organization	% Early Adopters	% Late Adopters	% Non-Adopters	Reasons for Resistance
Sales	20	50	30	In conflict with bonus pay system
Marketing	10	10	80	Doesn't fit current product mix
Operations	50	40	10	Causes minor restructuring of department

3. Create a stakeholder commitment scale.

- This scale compares stakeholders' current level of commitment to the level of commitment you need them to have before the change can occur. Use the stakeholder commitment scale to:
  - Identify the individuals involved in or affected by a change.
  - Identify the degree of effort needed to bring the individuals to a level of commitment necessary for change to be implemented successfully.
  - Establish priorities and develop appropriate action plans for the different individuals involved.

a) List the levels of commitment in the left-hand column of the matrix.

- Discuss each of the levels with your team to clearly define them.

b) List the stakeholders in the top row of the matrix.

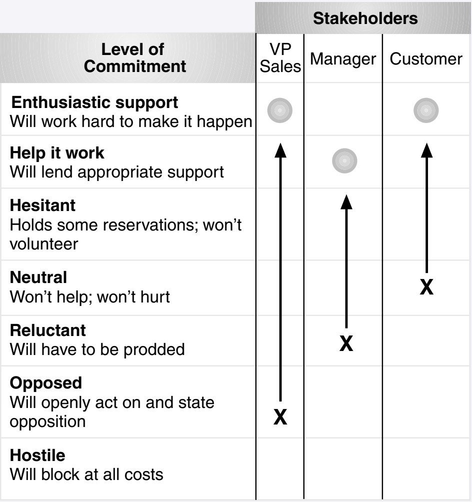
c) Use a circle to identify the level of commitment necessary from the stakeholders.

d) Use an X to identify the level of commitment currently demonstrated by the stakeholders.

e) Draw arrows from the X to the circle to show the degree of change that each stakeholder must undergo for the change to occur.

- Give those stakeholders with the greatest gap between the X and the circle the most attention in your planning efforts. Identify the factors that are creating the resistance in these groups and develop specific strategies to minimize or eliminate this resistance.

A Sample Stakeholder Commitment Scale



Level of Commitment	Stakeholders		
	VP Sales	Manager	Customer
Enthusiastic support Will work hard to make it happen	●		●
Help it work Will lend appropriate support	↑	●	↑
Hesitant Holds some reservations; won't volunteer	↑	↑	↑
Neutral Won't help; won't hurt	↑	↑	X
Reluctant Will have to be prodded	↑	X	
Opposed Will openly act on and state opposition	X		
Hostile Will block at all costs			

Change path visioning

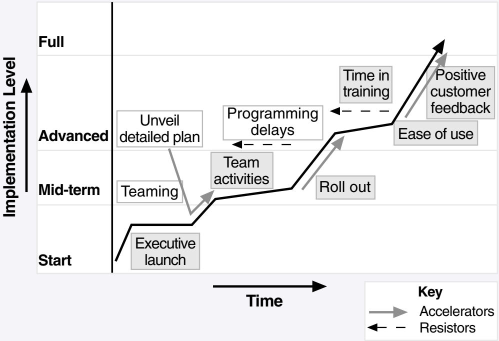
The change path visioning process shows change as a series of steps, with intermediate transition states occurring between the current and desired states. By understanding the transition stages and the forces that compel people to leave or stay at each stage, you can craft a workable plan for managing change.

1. Develop a visioning process.

- At each stage, ask:
  - What works here?
  - What does not work here?
  - What keeps people here?
  - What would happen if we stayed at this stage?
  - Why would people not want to be at this stage?

2. Use this information to plan movement to the next step until the desired state is reached.

A Sample Change Path Visioning Plan



In this example, some events, such as positive customer feedback and a detailed plan, will help to speed up the implementation pace while others such as programming delays and training will take more time and slow implementation. Visualizing when and where these events are likely to occur on the change path will help the design team create a realistic vision of the change process.

Change implementation and management

Change implementation links the organization's readiness for change with the visioning process.

Communication is important in creating and managing change. Ongoing communication:

- Keeps key stakeholders informed of progress.
- Enables stakeholders to plan resource allocation.
- Assists in aligning the project with other initiatives.
- Creates buy-in and support for the design.
- Prevents misunderstandings, which can impede or stop the project.

Use a communication plan as your primary mechanism to link the visioning process to the change.

1. **When creating a communication plan, ask:**
    - Who are the stakeholders?
    - What information needs to be conveyed to them?
    - How should the information best be conveyed (e.g., by email, meeting, etc.)?
    - How often should we communicate?

Tip Refer back to your commitment scale to determine who your stakeholders are. Typical stakeholders include:

- Managers whose budgets, results, schedules, or resources will be affected by the project.
- Customers targeted by the design.
- Suppliers who will provide materials or services for the design.
- Internal departments or groups whose work flows into the new design or whose work depends on the new design.

You may need to add additional stakeholders once you select your design concept.

2. **Record your answers to the questions above and distribute this information to the stakeholders in your organization.**

1.4 Identify Risks

Design projects face a number of risks. Anticipate where the key risks of failure are and develop a plan to address those risks:

- Identify known and potential risks for the project. When chartering a team, you may not know many of the risks because you have not yet chosen the specific design. Identify any known risks in the initial charter as well as potential risks that you anticipate.
- Indicate when and how the risks will be addressed. Also indicate at which point in the design process you expect to have the data to identify the real risks in the project. Update the risk assessment as the project moves forward.

Common potential risks include inadequate customer or business information, inadequate measures for the design, a rapidly changing environment, a tendency for the project scope to extend beyond the initial project boundaries, changing resource availability, complexity, and unproven or new technologies.

The task of identifying known and potential risks and defining a plan to reduce, minimize, or eliminate these risks is referred to as mitigating risks. Use a risk management plan to mitigate the risks associated with your design project.

What is it?

A risk management plan includes a categorization of known and potential risks and a plan to address those risks.

Why use it?

To mitigate any foreseen risk associated with the design project. Failure to recognize and address a significant risk could jeopardize an entire project.

How do I do it?

1. **Brainstorm a list of all known and potential risks.**
2. **Categorize the risks by their probability of occurrence and their impact on the project.**
   - The probability of a risk impacting a project ranges from "green light" to "red light."

Assessing the Probability and Impact of Risks

Probability of Occurrence	Low	Medium	High
High	Yellow Light: Proceed with caution ●	Red Light: Address before proceeding ●	Red Light: Do not proceed ●
Medium	Yellow Light: Proceed with caution ●	Yellow Light: Proceed with caution ●	Red Light: Reassess project ●
Low	Green Light: Proceed ●	Yellow Light: Proceed with caution ●	Red Light: Address before proceeding ●

Impact on Project

3. **For each risk in the yellow or red category, determine when and how you will address the risk in the design process.**

   - Different responses are appropriate based on the perceived severity of the risk. Risks in the yellow category can be addressed further downstream in the design process, but you must address risks in the red category before proceeding further. (Not all risks in the red category result in termination of the project but some action must be taken now.) Convert all risks in the red category to yellow or green before proceeding to the next major step in the project.

A Sample Risk Management Plan

Risk Description	Category	Action
Uncertainty in market growth rate	○ Yellow	Collect purchase information data during VOC.
Rapid changes in technology	○ Yellow	Repeat technology evaluation before concept design.
Success depends on management support	● Red	Launch awareness-building and organizational change.
Key project resources overcommitted	● Red	Gain commitment to free resources from champion before proceeding.
Project overlaps with ongoing reengineering effort	● Red	Reassess project scope and determine commonalities and differences between efforts.
No obvious customer for project	● Red	Stop project.

1.5 Hold a Tollgate Review

Include regular project reviews in your project schedule to ensure that your projects are successful. There are several levels of review:

- Milestone or tollgate reviews
- Weekly reviews
- Daily reviews

In addition, design projects have three unique reviews:

- A concept review

- A high-level design review
- A detailed design review

Because design projects are often complex, resource-intensive, and linked to accomplishing key business objectives, leadership reviews at the end of each step or phase of work are critical. Reviews help maintain leadership support, and the importance of design efforts makes ongoing communication with leadership essential.

Tollgate reviews provide opportunities to:

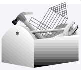
- Establish a common understanding of the efforts to date.
- Ensure alignment and reinforce priorities.
- Provide guidance and direction.
- Demonstrate support for the project.
- Provide ongoing coaching and instruction.
- Gather data across projects on strengths and weaknesses, enabling better planning and support.
- Ensure progress.

The milestone or tollgate reviews update everyone's understanding of how the progress of the project and new information affect the business case, the business strategy to which the design is linked, the schedule, the budget, and other resourcing needs. Be sure to review key risk areas and discuss plans to eliminate or address risks. Tollgate reviews are typically held at the end of each of the Define, Measure, Analyze, Design, and Verify steps.

The sponsor and team leader may meet weekly to discuss progress, changes, surprises, resource issues, and other factors affecting the project. This weekly meeting is an opportunity for joint problem solving as it enlists the sponsor's help in addressing organizational barriers or issues.

Team leaders may also hold daily twenty-minute check-ins with team members to surface problems as early as possible, review priorities, and answer questions.

Tollgate Review Form



What is it?

The Tollgate Review Form is a systematic way to ensure that the tollgate at the end of each step keeps the project on track.

Why use it?

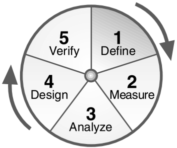
To provide consistency for design teams and help champions and sponsors review projects more efficiently and effectively.

How do I do it?

1. **Review the purpose of the step and discuss how you have achieved that purpose with this project.**
2. **Review the checklist of deliverables to ensure that these have been completed.**
3. **Answer the specific questions that describe what was done in this step and what will need to be done in the next step. Use a graphical Storyboard method to present this information at the tollgate review meeting.**

   Tip Some generic questions are listed in the sample form on the next page. Revise the questions to suit the needs of your particular organization and design project.

The Define Tollgate Review Form



Define:
Develop a clear definition of the design project

Deliverables:
- ☐ Project charter
- ☐ Project plan
- ☐ Organizational change plan
- ☐ Risk management plan
- ☐ Storyboard presentation

- What is the problem or opportunity you are trying to address?
- What is the specific process, product, or service you are (re)designing?
- What are the strategic drivers for the project?
- Why is the DMADV method right for this project?
- What is the scope of the project?
- What is the project timeline and completion date?
- Are additional team resources needed?
- What are the major risks associated with the project? How will these risks be addressed?
- How will you ensure the organization embraces and supports changes resulting from the design?
- What barriers have you encountered?
- Is your project plan on track?
- What are your key learnings from the Define step?
- What are your next steps?

Measure
Customer Requirements

Why do it?

To translate the Voice of the Customer (VOC) into CTQs.

Tools used in this step:

- The Customer Segmentation Tree
- The Data Collection Plan
- Customer research tools:
  - Interviews
  - Contextual Inquiry
  - Focus Groups
  - Surveys
- The Voice of the Customer Table
- Affinity Diagrams
- The Kano Model
- Performance Benchmarking
- The Quality Function Deployment (QFD) Matrix
- The CTQ Risk Matrix
- The Multistage Plan
- Tollgate Review Forms

Outputs of this step:

- Prioritized CTQs
- Updated risk managment plan and multistage

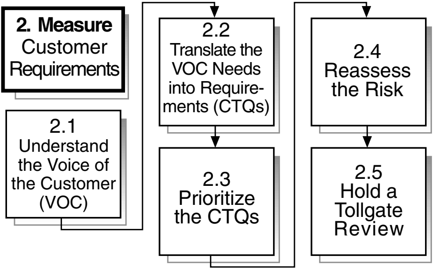
project plan, if appropriate

- A tollgate review and updated Storyboard

Key questions answered in this step:

- Who are the customers of the process, product, or service?
- Who are the most important customers?
- Do all customers have the same needs? If not, how can we segment customers?
- How do we collect data on customers' needs?
- How do we understand customers' most important needs?
- What are the critical design requirements to meet the customers' needs?
- What are the performance targets that the design should meet to satisfy customers?
- What are the risks associated with not meeting all of the performance requirements immediately?
- Is a phased approach necessary to meet all of the key CTQs?

How do I do it?



2.1 Understand the Voice of the Customer

The term *Voice of the Customer* describes customers' needs and their perceptions of your process, product, or service. It includes all aspects of the relationship with the customer with regard to quality, cost, and delivery.

Note: The Measure step focuses on understanding customers' expressed and latent needs. However, understanding customer requirements is not limited to the work in the Measure step. Customer research occurs throughout the DMADV process. You may gather market information in the Define step to build a business case for the project. You might involve customers in the concept review at the end of the Analyze step and in the development of high-level and detailed designs in the Design step. Customers also provide feedback on prototypes and can work closely with the design subteams in the Design step, giving frequent, rapid feedback as the design unfolds. And you may ask customers to participate in the pilot in the Verify step; however, their activity in the pilot is simply to help with minor adjustments to the overall system (i.e., you should not be discovering important new requirements in the pilot).

Understanding the Voice of the Customer is critical. VOC data helps an organization:

- Align design and improvement efforts with the business strategy.
- Decide what processes, products, and services to offer or enhance.
- Identify the critical features and performance requirements for processes, products, and services.
- Identify the key drivers of customer satisfaction.

Tip If you are collecting VOC data to design a new process, product, or service, remember that what customers say may not match their behavior. For example, when asked how long they are willing to wait on the phone, customers may say one minute, when in fact, they are only willing to tolerate twenty seconds when they are put on hold in a real situation.

Be sure to find out what your customers need and will tolerate instead of what their perception might be.

(For more information on uncovering customer needs, see Richard B. Chase and Sriram Dasu's article, "Want to Perfect Your Company's Service? Use Behavioral Science," in the June 2001 issue of the *Harvard Business Review*.)

To understand the Voice of the Customer, you need to:

- Identify the customers.
- Collect customer needs data.
- Analyze the needs data.

The outcome of understanding the Voice of the Customer is a list of prioritized needs.

2.1.1 Identify the customers

How do I do it?

1. **Identify potential customers whose interests and viewpoints are important and others whose perspectives can add value to the design.**
    - Include:
        - Customers who buy your products or services.
        - Customers who stopped buying your products or services.
        - Leading thinkers and other experts.
        - Technology leaders in the industry.
        - Strategic partners.
        - Stakeholders.

- Include your internal customers and stakeholders. Also include those who buy alternative products and services (i.e., customers who purchase from direct competitors as well as customers who choose quite different products or services to meet their needs. For example, if your organization produces frozen foods, alternative products and services could include purchasing fresh organic produce or eating in restaurants.)

2. **Identify potential customer segments.**

   - Often there is no single Voice of the Customer. Different customers or types of customers have different needs and priorities. These different types of customers can be referred to as customer segments.

     If you suspect different groups will have different needs and that these differences will influence the design of your process, product, or service, think in terms of customer segments. Later, if data shows that customers have similar needs across some segments, you may be able to combine these segments. The design challenge will be to address multiple requirements across selected segments.

   - To determine if segmentation is feasible for your market, ask:

     - Can we rank customers in order of importance?
     - Does the expected return on investment for the identified customer segments warrant a custom solution? How will this impact subsequent design phases, manufacturability, and marketing?
     - Can we easily reach the customers in each segment to collect the data we need?
     - Will the targeted customers respond to research efforts?

Tip When segmenting *business* customers, consider:

- Company demographics such as industry, size, and location.
- Operating variables such as technology used, product used, brand used, technical strength or weakness, and financial strength or weakness.
- Purchasing approach such as purchasing organization, powerful influencers, and policies.
- Situational factors such as urgency of order fulfillment, product application, and size of order.
- Personal characteristics such as buyer/seller similarity and attitudes toward risk.

When segmenting *residential* customers, consider:

- Geography.
- Demographics such as age, sex, education, and income.
- Product usage such as rate of use, end use, brand loyalty, and price sensitivity.
- Purchasing roles such as initiator, influencer, and user.
- Psychological variables such as motivation, attitudes, learning style, and personality.

(Adapted from the 1984 *Harvard Business Review* article "How to Segment Industrial Markets" by Benson P. Shapiro and Thomas V. Bonoma, Vol. 84, No. 3)

- Use a Customer Segmentation Tree to help you segment different types of customers.

Customer Segmentation Tree

What is it?

A Customer Segmentation Tree is a breakdown of customer segments using a Tree Diagram and a nesting approach. The key to using the nesting approach is to maintain a balance between simplicity and enrichment.

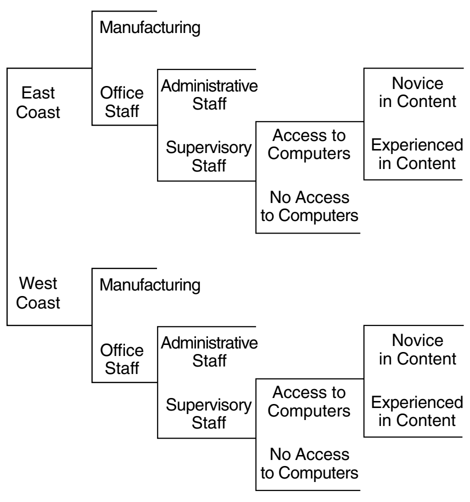
Why use it?

- To define various customer segments
- To graphically display relationships between complex levels of segments

How do I do it?

1. **Define the first level of segmentation, and list this level on the left side of the Tree Diagram.**
   - The first level often defines segments with information that is easy to obtain (such as geography or demographics).
2. **Split the first level of segmentation into subsequent levels, adding more detail with each step. List each subsequent level to the right of the higher level, as a branch off of the higher level segment.**
   - The middle levels divide the first-level segments into more detailed descriptions such as operating variables or purchasing approaches. The inner levels focus on information (such as situational factors or personal characteristics) that can be the most difficult to obtain, but is often the most useful.

A Sample Customer Segmentation Tree



The Customer Segmentation Tree in this example shows how to deliver training to participants at multiple sites without requiring anyone to travel. Each path through the tree represents a different customer segment.

3. Prioritize the customer segments.

- Select the most important customer segments using factors such as:
  - The size of the customer segment.
  - Profit margins.
  - The frequency and volume of business transactions.

- Focus on the segment(s) whose needs align with your business strategies, including:
  - Your company's current strengths and plans.
  - New challenges and directions your company will successfully embrace.
  - Profit from serving existing customers.
  - Growth from serving new customers.

Tip Avoid immediately settling on the "classic" segmentation dimensions such as geography or demographics. These may be useful ways of segmenting existing business, but the new design may require different segments based on the charter and the strategic objectives of the project. Take an unbiased look at the segmentation options available before finalizing your choices.

2.1.2 Collect customer needs data

Customers may communicate directly with you when they have a problem, but in other instances, you may have to actively seek out information on issues that relate to customers' needs. There are two basic systems you can use to collect customer needs data and capture customer information–*reactive systems* and *proactive systems*.

Reactive systems:

- Are initiated by the customer (e.g., as complaints, returns, credits, and warranty claims).
- Provide information about a current process, product, or service.
- Can be biased because they only collect data from those customers who have a need to contact the company (usually because they are unhappy).
- Generally gather data from current and former customers on issues or problems, unmet needs, or their interest in a particular product or service.

Proactive systems:

  - Are initiated by your organization rather than the customer (e.g., as market research, customer interviews, surveys, and focus groups).
  - Provide information on potential new products or new uses for existing products.
  - Can be less biased than reactive systems and more likely to uncover latent needs (if the systems are designed well).
  - Generally gather data from selected customer groups such as current customers, former customers, noncustomers, and competitors' customers.

- Reactive systems help capture all of the ways in which customers communicate their needs. Most businesses already have daily contact with their customers in which customers share their opinions about what is important to them. Organizations generally use this contact information to solve a customer's immediate needs. But you should explore this often-underused source of information before attempting to gather new information. You can learn a lot about improving existing processes, products, and services by putting extra effort into categorizing and analyzing the data from reactive sources, and reviewing this data periodically to identify patterns, trends, and other opportunities.

- Proactive systems help capture data on unstated needs and validate your assumptions about customer needs. In proactive systems, *you* initiate the contact with customers. You design and undertake targeted customer contact to gather information specifically related to your project. Ideally, your contact will include face-to-face interviews or customer visits. To maximize efficiency, be sure to integrate your efforts with any ongoing customer contact in your organization (i.e., request that your customer service or marketing staff ask additional questions during regular contact with customers, or ask to observe customers in their workplace during a scheduled visit).

Note: An advantage to using proactive research is that it allows you to gather information on both stated and unstated needs and avoid some of the bias associated with reactive data collection methods.

How do I do it?

Tip Start your data collection process by collecting reactive data because it is generally easier to obtain and can provide a basic understanding of customer concerns (allowing you to better focus your proactive work). Follow up with information from proactive systems to better expand your understanding of customer needs and to quantify the importance that customers place on various characteristics.

1. **Collect and summarize existing data.**
   - Existing data can lead to hypotheses about customer requirements that you may decide to verify with further proactive customer research.
   - Some data may already be collected, but you may need to institute processes to locate, extract, and summarize the data.
2. **Analyze this data using the appropriate tools (e.g., Pareto Charts or Control Charts).**
   - Make a few preliminary conclusions from the relevant existing data.
3. **Determine which preliminary conclusions you need to validate with new customer research.**
   - Determine if you reached the right conclusions from the existing data.

4. **Consider additional broad questions to understand your customers' needs and extend your thinking beyond existing products and services.**

   - Use proactive research to determine what else you need to learn to understand customer requirements that go beyond responses to current products and services.

   Tip Use customer research to move toward greater certainty about what customers need and what priorities they put on those needs. Keep in mind that gathering and analyzing customer information costs time and money. On one side are the costs of risks from having too little information. On the other side are the costs associated with gathering more information. Find the balance point between the risk you can tolerate and the certainty you can afford.

5. **After identifying the scope of data collection, develop a plan to collect the data.**

   - Ask:
     - What are the goals for data collection?
     - What additional data do we need to gather?
     - What is the right level of detail at which to collect data?
     - How do we collect true "needs" information?
     - What methods should we use to collect the data?
     - How should we record the data?
     - What is the appropriate sample size?
     - How much piloting/preliminary analysis is needed?
     - How will we reduce sources of error and variation in the data collection?

Use a VOC Data Collection Plan form like the one on the following page to record the details of your plan.

VOC Data Collection Plan Form

PROJECT:

Who	What and Why
Customers and Segments	Indicate specifically what you want to know about your customers. Develop customized versions of the following questions that you can ask during face-to-face interviews: • What's important to you? • What's a defect? • How are we doing? How do we compare to our competitors? • What do you like? What don't you like?

Sources

Put an X next to the data sources you think will be useful for this project.

Reactive Sources

- ☐ Complaints
- ☐ Problem or service hotlines
- ☐ Technical-support calls
- ☐ Customer-service calls
- ☐ Claims, credits
- ☐ Sales reporting
- ☐ Product-return information
- ☐ Warranty claims
- ☐ Web page activity
- ☐ Other:

Proactive Sources

- ☐ Interviews
- ☐ Focus groups
- ☐ Surveys
- ☐ Comment cards
- ☐ Sales visits/calls
- ☐ Direct observation
- ☐ Market research/monitoring
- ☐ Benchmarking
- ☐ Quality scorecards
- ☐ Other:

Summary: Which, How Many, How, and When

On a separate sheet, summarize your plans to gather and use reactive and proactive sources. Indicate how much data you will get, how you will get it, and when. Include, for instance, the number of interviews or surveys you plan to conduct, which customers you will contact, when you will start and end the data-collection process, and so on.

Customers don't always express their true needs. They often mistakenly express:

- Perceived needs
- Misstatements of use
- Features and functions
- Quality characteristics or measures, or
- Targets

as real needs, making the discovery of their true needs more difficult.

To ensure that the VOC data collection focuses on true needs as much as possible, ask questions to reveal the needs that underlie what customers say. A customer who expresses a perceived need by saying "I want a taxi within ten minutes of calling for one" may really be saying "I want to reach my final destination on time." A customer who provides a product or service feature by stating "I need a performance summary report every day" may really be saying "I need a way to monitor service performance every day." And a customer who says "I'm concerned about average speed of answer" has translated his customer need into design language; he may actually be saying "I'm waiting too long on the phone."

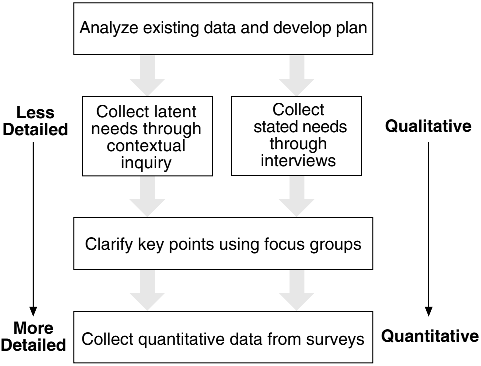
Tip When you collect VOC data, focus on the true needs as much as possible. You can then identify true needs as:

- Stated needs: Needs that customers verbalize, often expressed in response to proactive data collection questions or through reactive means such as complaints.
- Latent needs: Needs that customers may not verbalize, either because the customers think they are too obvious to state or because customers are themselves unaware or unable to formulate the need.

> Customers often fail to verbalize latent needs for new designs so make sure that you uncover and collect latent needs data.

An exploration of needs data begins with an analysis of existing data, continues with data collection from individuals and groups of similar customers, and ends with a verification of the findings from many customers.

The Data Collection Process



When collecting VOC information:

1. Proceed from high level to detailed.
    - Often, collected needs are too general (e.g., "good customer service" is not specific enough to design customer service operations). However, because data collection is expensive and time-consuming, it is useful to generate some ideas about the general areas that you need to explore before plunging into details. The needs obtained at the most detailed level will then help you generate design solutions.

2. Proceed from qualitative to quantitative.
    - Focus your initial VOC effort on identifying the qualitative categories of needs and on uncovering new needs. After identifying the qualitative categories that you should gather information in, you can then quantitatively prioritize the detailed needs.

Use interviews, contextual inquiries, focus groups, and surveys as proactive tools to capture VOC data. Avoid using surveys or questionnaires until you have had in-depth discussions with individuals or focus groups because these tools don't uncover new needs; they help verify needs identified through other means. Use surveys and questionnaires to collect quantitative information on priorities and to validate your conclusions by checking with a larger group.

What is it?

An interview collects stated needs from the customer's perspective on a variety of issues regarding the process, product, or service. Information from interviews is recorded word for word from the customer's responses.

Why use it?

- To identify what is important to customers
- To uncover new and unexpected information
- To reach people who may not participate in other data-collection methods
- To confirm your design team's theories

- To add information that clarifies an issue and helps you better understand why an issue is important to customers
- To validate conclusions and themes

How do I do it?

1. **Select a cross-section of potential customers.**
    - Include customers from all key segments.
2. **Prepare for the interview.**
    - Define the objective of the interview.
    - Determine what information you need.
    - Decide specifically whom to interview.
        - Select people to interview based on the range of customer perspectives needed. The individuals selected may need to represent a key customer segment (such as an industry) as well as a function (such as sales). The individual may also need to represent the user, the "approver," or the purchaser of the product or service.
    - Set a time limit for the interview.
    - Write the interview questions and develop an interview guide.
    - Train the interviewers.
    - Schedule the interview.

Caution: Interviewers can inadvertently introduce bias by the wording of their questions and with their verbal and nonverbal responses to answers. To reduce this bias, use experienced professional interviewers or spend sufficient time wording, testing, and revising the questions and question sequences before conducting the first interview. Interviews also have the disadvantage of a small sample size; the data analysis may require qualitative tools and can be time-consuming.

3. **Conduct the interview.**

   - Whenever possible, have two people conduct each interview. Allow one person to focus on the questions and interaction while the other person takes verbatim notes.
   - Conduct the interviews face-to-face, by phone, or by videoconference. (Phone or videoconference interviews are particularly useful when customers are geographically dispersed.)
   - Be clear about the purpose of the interview. Let the interviewee do most of the talking, and listen actively. When setting up the interview, inform the interviewee of the time commitment (most interviews last 1–2 hours) and have a backup plan if time needs to be cut short.
   - Open the interview by building rapport and trust. Tell the respondent he or she may ask questions at any time. Explain note-taking methods and ask permission to record answers. Address confidentiality issues and have a backup plan if permission is not granted. Before asking the first question, solicit and address any questions or concerns.
   - During the interview, be relaxed and conversational. Check your understanding and ask probing questions to ensure that answers are complete. Watch the time and pace yourself, covering all of the key points within the time limit. If you want the respondent to rate or rank items, ask at the end of the interview.
   - At the end of the interview, thank respondents for their time and participation. Ask if you can be in touch in case you need any clarification. If

your organization is willing, ask respondents if they would like a summary of the findings.

4. **After the interview, summarize your learnings while the interview is fresh in your mind and record any ideas that could enhance future interviews.**

Contextual Inquiry

What is it?

Contextual inquiry is a data-gathering method using a master/apprentice model rather than an interviewer/subject model to collect latent needs about a process, product, or service.

The attitude of apprenticeship is one of curiosity and learning. The person doing the work is an expert at his or her work and the apprentice pays attention to the details in an open, nonjudgmental way and asks exploring questions. The questions help the person doing the work reflect on the work; the reflection helps the questioner understand the work.

Why use it?

- To uncover the unstated details of a work process
- To discover new uses and features for processes, products, and services
- To explore actual vs. intended uses
- To identify latent as well as stated needs

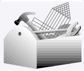
How do I do it?

1. **Visit a customer's workplace to observe work as it happens.**
2. **Collaborate with the customer in understanding his or her work.**
   - Be sure to maintain your perspective as the apprentice throughout the inquiry.
3. **Interpret the findings from your observations.**
   - If possible, combine the perspectives from multiple contextual interviews to produce an overall picture.

Tip The questions for a contextual inquiry grow out of the observations of the work. Do not develop a rigorous interview guide for a contextual inquiry.

Caution: Contextual inquiry is not as useful if the design is not connected to a current process, product, or service. It also has the disadvantage of a small sample size.

Focus Groups



What is it?

A focus group is a planned and facilitated discussion that records interaction among participants and reveals factors that influence participants' attitudes, feelings, and behavior.

Why use it?

- To define and understand the requirements of each customer segment

- To understand the priorities of each customer segment
- To generate synergy among participants with common interests (which stimulates new ideas)
- To allow open-ended comments and provide insight into opinions, attitudes, and opinion shifts
- To provide insight into complex behaviors or motivations
- To deepen your understanding of participants' thought processes

How do I do it?

1. Plan the focus group session.

- Determine why you are holding the focus group.
- Determine the criteria for whom to involve in the focus group. (Focus groups usually include 7–13 people.) Identify which customer segment each focus group will represent and choose an experienced moderator(s) to help you plan and conduct the sessions.
- Decide on a structure and flow for the discussion. (Most focus groups sessions consist of in-depth discussion on a limited number of topics.)
- Determine the location and schedule. (Sessions usually last 2–4 hours.)
- Determine what resources you will need for a successful session.
- Limit the number of questions.

Tip Conduct at least three focus groups to ensure that the data is representative. If the customer segments have different needs, complete at least one focus group with each segment to verify that they do have different needs and to understand how their needs differ. Continue conducting focus groups until you fail to learn anything new.

2. Conduct the focus group session.

- Introduce the purpose, participants, topic, and expectations of the session.
- Set the ground rules for discussion.
- Facilitate the discussion.

3. Summarize and analyze your findings.

Like interview questions, focus group questions should be predetermined, open-ended, logically sequenced, nonthreatening, clear, and simple. In addition, focus group questions should move from broad topics to specific ones.

> ***Caution:*** Focus groups are often difficult to facilitate and manage. Typically, the interviewer has less control over the interaction than in individual interviews, the data analysis requires skills in qualitative interactive research, and the logistics can be very challenging. Be prepared to provide an experienced moderator to ensure a successful outcome. It may be helpful to use a moderator who is not directly involved in or affected by the project.

surveys

What is it?

A survey is a structured data collection method that helps to verify the conclusions identified using previous methods.

Why use it?

- To efficiently collect and quantify information from a large population
- To verify and prioritize needs identified by other data collection methods
- To easily quantify data
- To provide anonymity

Interviews, observations, and focus groups identify needs. Surveys follow these tools and verify that the needs are, in fact, characteristic of the whole segment that the participants represent.

> ***Caution:*** Surveys have several disadvantages including high expense and a low response rate. Be careful in your use of them.

How do I do it?

1. Determine the objectives and appropriate type(s) of survey (i.e., mail, phone, electronic, individual, or group).

2. Determine the sample size.

- Sampling involves collecting data from a portion of the population and using that portion to draw conclusions or make inferences about the entire population. Sampling may be necessary because collecting data from everyone in the population may be too expensive or too time-consuming. When designed well, a relatively small amount of data can often provide very sound conclusions.

Tip Use the following four factors to determine how many samples are needed:

1. What type of data (discrete or continuous) you will collect
2. What you want to do (e.g., describe a char-

acteristic [such as the mean or proportion] for a whole group with a certain precision [+/- "x" units], or compare group characteristics [i.e., find differences between group means or group proportions] at a specific power [i.e., the probability you will use to detect a certain difference])

3. What you think the standard deviation will be
4. How confident you want to be (usually 95%)

Tip Because sampling can be complex, enlist the help of a statistician in determining sample size.

3. **Identify the information you need to collect.**
4. **Write the survey questions and develop measurement scales.**

- Prevent response bias by avoiding:
  - Loaded questions: Value-laden language that is likely to bias the response (e.g., "Do you support ridiculous Proposition X?").
  - Questions that lead respondents toward a particular answer (e.g., "Isn't it true that men are more likely to speed than women?").
  - Ambiguity: Questions that are not focused enough to obtain the information you need (e.g., "How often do you buy fast food?" vs. "In the last ten times you've eaten out for lunch, how often have you purchased each of the following types of food. . .?").
  - Too much or too little specificity.
  - More than one topic or issue per question.
- Ensure that participants can answer all questions meaningfully by using specific options or

scales (i.e., use a limited number of open-ended questions).

Tip An interval scale is the most common type of measurement scale used in surveys. An interval scale is a continuum with equal intervals marked off and often includes an odd number of points to provide a neutral midpoint. Place the options on the scale in order (e.g., low = 1 and high = 5) and ensure that the difference from one option to the next is consistent across the scale. Use interval scales to measure the level of:

- Agreement (strongly disagree to strongly agree).
- Satisfaction (extremely dissatisfied to extremely satisfied).
- Importance (extremely unimportant to extremely important).

5. Specify the requirements for coding.

- Be clear about how you will handle the survey responses so that the survey's design will give you the information that you are seeking.
- Define, up front, how you will "code" the survey answers after the surveys are completed and returned (e.g., to code responses about customer segments, you might label the parts of the survey that deal with customer segments).

6. Create the survey.

7. Test, pilot, and finalize the survey.

2.1.3 Analyze the needs data

How do I do it?

1. **Check the VOC statements collected in the previous step.**
   - Review the language data to remove duplicates.
   - Reword the data as necessary to reflect consistent phrasing in the customer's voice (e.g., translate all negatives into positive statements).
2. **Separate the needs from solutions, targets, and measurements.**

   Tip Save any functions or solutions until later when you develop concepts. Consider them at that point, along with the other solutions you will develop. Save targets and measurements until you translate the customer needs into requirements. Consider the measurements along with the other measures generated by your team; consider the targets during the target-setting process.

   - Use a VOC Table to assist in sorting needs from other types of comments.

What is it?

A Voice of the Customer Table helps sort needs from solutions, targets, measurements, and other types of comments.

Why use it?

- To structure a sorting process involving large quantities of data
- To help explain the sorting process to others

How do I do it?

1. Construct a table by listing the categories (e.g., solutions, targets, measurements, and needs) across the top row of the table and listing customer verbatims in the left column.

2. Identify what category each verbatim applies to. Place an X in the corresponding cell.

3. For each verbatim that is not a need, spend a few moments with your team to translate the customer statement into the need underlying the statement. Add that need to the table and continue on with the next verbatim.

A Sample VOC Table

Customer Statement	Solution	Measure	Target	Need
Need agent to call after order is received	X			
Need order fulfilled in 24 hours			X	
Need high order-fulfillment rate		X		
Need stock replenished before it runs out				X

3. Organize the needs.

- Select the needs from the VOC Table and sort them into common levels of detail using an Affinity Diagram.

What is it?

An Affinity Diagram organizes large amounts of language data (ideas, opinions, issues, etc.) into groupings based on the natural relationships between the items.

Why use it?

- To organize and summarize natural groupings among a large number of ideas
- To categorize the customer verbatims of the VOC

How do I do it?

1. Sort through all of the information you have collected (from interviews, focus groups, surveys, etc.) and select those comments that reflect needs related to the design project.

2. Write these needs on cards or Post-it® Notes.

- Keep the need statements used in the Affinity Diagram in the customer's own language if at all possible. Avoid using single words; use, at minimum, a verb and a noun.

Tip In general, the more specific and concrete the statement, the more valuable it will be. For example, a vague statement such as "I want good service" provides no clue about what you can do to make that customer happier. Specific statements that relate to a particular requirement, such as "I want my questions to be answered correctly the first time," provide much more information about that customer's needs and expectations.

Note: For more detail on selecting and sorting customer statements, see *Voices into Choices: Acting on the Voice of the Customer* by Gary Burchill and Christina Hepner Brodie, Oriel Inc., Madison, WI.

Tip A "typical" Affinity Diagram has 40–60 items; it is not unusual to have 100–200 ideas.

3. Have team members simultaneously sort the ideas (without talking) into 5–10 related groupings.

- Have team members move each Post-it® Note where it best fits for them. Tell them not to ask before moving a Post-it® Note; simply move any note that belongs in another group.

Note: Sorting will slow down or stop when each person feels sufficiently comfortable with the groupings.

Tip Sort in silence to focus on the meaning behind and connections among all ideas, instead of the emotions and "history" that often arise in discussions.

Tip As an idea is moved back and forth, have team members try to see the logical connection that the other person is making. If this movement continues beyond a reasonable point, have them agree to create a duplicate Post-it® Note.

Tip It is okay for some notes to stand alone. These "loners" can be as important as others that fit into groupings naturally.

4. **Use consensus to create summary or header cards for each grouping.**

   a) Gain a quick consensus on a phrase that captures the central idea/theme of each grouping; record it on a Post-it® Note and place it at the top of each grouping as a *draft* header card.

   b) For each grouping, agree on a concise sentence that combines the grouping's central idea and what all of the specific Post-it® Notes add to that idea; record it and replace the draft card with this *final* header card.

   Tip Spend the extra time you need to create good header cards. Strive to capture the essence of *all* of the ideas in each grouping. Shortcuts here can greatly reduce the effectiveness of the final Affinity Diagram.

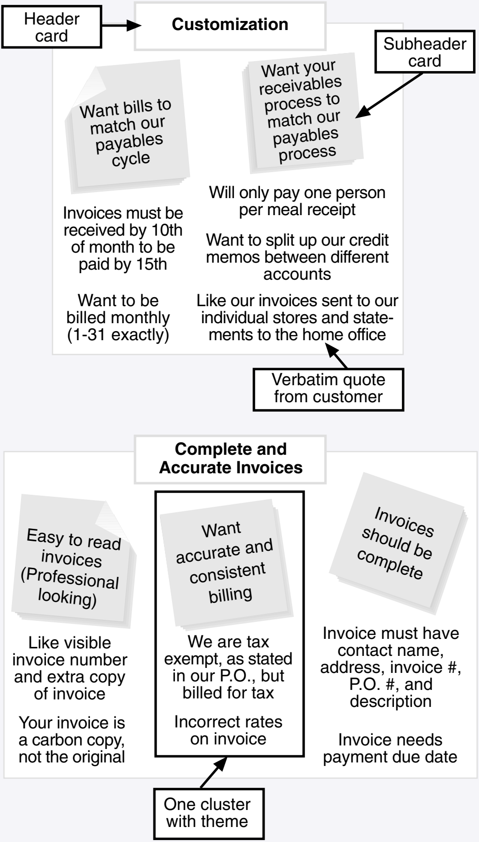
   Tip It is possible that a note within a grouping could become a header card. However, don't choose the "closest one" because it's convenient. The hard work of creating new header cards often leads to breakthrough ideas.

   c) Divide large groupings into subgroups as needed and create appropriate subheads.

   d) Draw the final Affinity Diagram connecting all finalized header cards with their groupings.

In the example on the next page, data collected on the "billing process" is analyzed using an Affinity Diagram.

A Sample Affinity Diagram



Header card

Customization

Subheader card

Want bills to match our payables cycle

Want your receivables process to match our payables process

Invoices must be received by 10th of month to be paid by 15th

Want to be billed monthly (1-31 exactly)

Will only pay one person per meal receipt

Want to split up our credit memos between different accounts

Like our invoices sent to our individual stores and statements to the home office

Verbatim quote from customer

Complete and Accurate Invoices

Easy to read invoices (Professional looking)

Like visible invoice number and extra copy of invoice

Your invoice is a carbon copy, not the original

Want accurate and consistent billing

We are tax exempt, as stated in our P.O., but billed for tax

Incorrect rates on invoice

Invoices should be complete

Invoice must have contact name, address, invoice #, P.O. #, and description

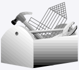
Invoice needs payment due date

One cluster with theme

4. **Check the needs list for completeness.**

   - Use the Kano Model to ensure that you have not omitted any critical needs.

Kano Model



What is it?

The Kano Model helps to describe which needs, if fulfilled, contribute to customer dissatisfaction, neutrality, or delight. It identifies the:

- "Must Be" needs: Those needs that the customer expects (e.g., airline safety). If Must Be needs are unfulfilled, the customer is dissatisfied; however, even if they are completely fulfilled, the customer is not particularly satisfied.
- "More Is Better" needs: Those needs that have a linear effect on customer satisfaction (e.g., faster airport check-ins). The more these needs are met, the more satisfied customers are.
- "Delighter" needs: Those needs that do not cause dissatisfaction when not present but satisfy the customer when they are (e.g., serving hot chocolate chip cookies during an airline flight).

Why use it?

To identify and prioritize the full range of customers' needs.

How do I do it?

1. **Gather sorted customer needs from an Affinity Diagram.**

2. **Review the themes from the Affinity Diagram and sort them into the three categories in the Kano Model (Must Be, More Is Better, and Delighters).**
3. **If there are very few or no needs listed in one of the categories, collect additional customer data.**

   Tip Customers generally cannot express what their basic expectations are or what would delight them. Therefore, when you prioritize customer needs based on what they say is important, remember that customers generally identify only More Is Better characteristics. Use other means (such as direct observation of customer use) to identify and set priorities for Must Be needs and Delighters.

4. **After you have collected additional data, return to the Kano categories and complete the sorting of customer needs.**
5. **Prioritize the customer needs you will use when you develop the CTQs.**

   Tip Include all Must Be needs because, if absent, they will create customer dissatisfaction. Consider the importance of More Is Better needs to provide steady and strong increases in satisfaction. Include a few Delighters that will increase satisfaction dramatically. Also consider how these categories relate to your company's competitive advantage.

Customer Expectations for a Hotel Room

	Must Be	More Is Better	Delighters
Hotel Room	• Bed • Clean towels • Phone • Coffee maker	• Number/ thickness of towels • Size of room	• Fruit basket upon arrival • Balcony • Free movies

Tip Customer needs change over time. A Delighter today might be a Must Be need tomorrow. Different customer segments might also have different needs. For example, a business traveler might consider an iron in a hotel room a Must Be need but the size of the desk's work surface a More Is Better need. However, a family traveling on vacation might consider free movies and video games a More Is Better need and consider the desk size irrelevant.

Tip Double-check your work to ensure that you have not inadvertently missed a Must Be need. And because you gain competitive advantage through Delighters, identify additional Delighters if they are few in number.

5. **Establish priorities for the detailed needs.**

- There are two possible types of prioritization–*qualitative prioritization* and *quantitative prioritization*.
- Qualitative prioritization uses low/medium/high scales, extracts priorities from the frequency of being mentioned, and uses the Must Be, More Is Better, and Delighter Kano Model classifications.
- Quantitative prioritization uses rating or ranking scales like the ones listed below.

Quantitative Prioritization Scales

Scale	Description
Absolute importance	Rate on a scale of 1(least important) to 5 (most important)
Relative importance	Assign 100 points between needs; determine the relative importance through a series of pairwise comparisons (e.g., A is more important than B).
Ordinal importance	Rank-order from most to least important

Tip Because quantitative prioritization uses customer ratings and rankings to prioritize needs, it is the recommended approach to capture and understand the Voice of the Customer.

2.2 Translate the VOC Needs into Requirements (CTQs)

In most situations, customers express their needs in everyday language. But the design team needs to express the requirements to design a process, product, or service in precise technical terms. Therefore, you must use a translation process to convert the needs of the customers into the language of the design team. These translated requirements, expressed in business or engineering language, are the CTQs.

Note: In some cases, the translation from needs to measures is obvious so this substep may be unnecessary. For example, the need "quick response" can be directly translated into the measure "speed of response." But for less tangible needs (such as "I want to feel welcome when I walk into your business"), thinking first about characteristics of the need (e.g., feeling welcome includes politeness, friendliness, etc.) will help in identifying measures to meet these needs.

Remember that each CTQ should have:

- A quality characteristic that specifies how the designed process, product, or service will meet the customer need.
- A quantitative measure for the performance of the quality characteristic.

  (**Note:** Remember to create clear operational definitions of the measures for the CTQs.)
- A target value that represents the desired level of performance that the characteristic should meet.
- Specification limits that define the performance limits that customers will tolerate.

Necessary Components for Two Sample CTQs

CTQ	Customer Need	Quality Characteristic	Measure	Target	Specification Limits
Designing a pizza delivery service	"I want my pizza to be hot when I get it."	Hotness of pizza	Temperature (in °F)	125°F	Lower limit = 120°F; Upper limit = 130°F
Customer service	"I want the right answer from the first person I speak with on the phone."	Phone transfers	Number of transfers before the customer receives an answer	Zero transfers	98%

To translate the VOC needs into requirements (CTQs), you need to:

- Generate the CTQs.
- Set targets and specifications.

2.2.1 Generate the CTQs

To generate CTQs for each of the prioritized needs from substep 2.1:

1. **Select the appropriate level of need to focus on.**

   Tip Typically, teams use lower level needs to generate measures. If there are 30–60 needs at this lower level, the task of generating measures can be quite daunting. To make this task easier, you should initially develop characteristics for the first- or second-level needs and use the QFD Matrix (explained in greater detail later in this chapter) to identify the most important characteristics. You can then generate measures using the third-level needs for only the most important characteristics.

2. **For each need at the selected level, brainstorm 1–3 quality characteristics that could address that need.**

3. **Develop measures to quantify the characteristics.**

   Tip There is no magic formula for generating measures; they are based on the knowledge of your team, the data obtained from the VOC study, and discussions between team members. Often the first few measures take a long time to generate; the task becomes easier as you get a feel for the process.

In general, the more detailed the level of analysis, the more useful and relevant the measures.

2.2.2 Set targets and specifications

1. **Set targets and specifications either:**

   - Qualitatively, using the importance of the CTQs (as expressed by the customer), competitor performance information, and internal capabilities data.
   - Quantitatively, using mathematical models of the relationship between customer satisfaction and performance.

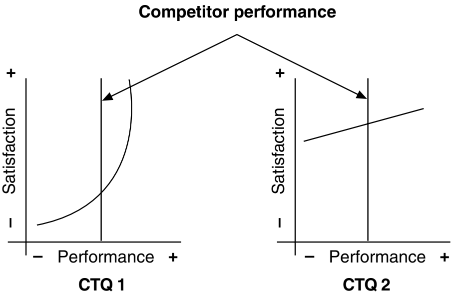
   Caution: Determining targets and specification limits is not always easy. Target setting is both an art and a science. Targets are often set arbitrarily because organizations lack information on benchmarks and satisfaction/performance relationships (which ultimately impacts the quality of the design). Even if you cannot use formal mathematical methods, some thought and analysis is critical to setting good targets.

2. **If you have limited resources, set the highest performance targets for those measures that have the potential of providing the highest rewards.**

   - Set targets to exceed competitor benchmarks for the most important CTQs but balance this expectation against the costs of meeting a high performance target and against the internal capabilities of the organization. If the organization is not capable of performing at a high level without a significant cost investment, then the returns may not justify the costs.

   In the following example, higher performance targets are more critical for CTQ 1 than for CTQ 2.

Satisfaction/Performance Functions



For CTQ 1, the curve between satisfaction and peformance is steep so making an investment to set a higher performance target than the competition will produce greater rewards. But failing to at least meet the competition's level of performance will result in a significant decrease in satisfaction.

For CTQ 2, the risk/reward situation is not so dire. The relationship between performance and satisfaction is shallower. As a result, a "low investment" solution of setting the performance target at or even below the competition's performance will not result in a large impact on satisfaction.

Use Performance Benchmarking to compare your organization's performance to the performance of others.

What is it?

Performance Benchmarking examines the processes, products, and services of market leaders to see how well they perform, and compares your performance capabilities against the benchmark. It is another source of information to help you define measures and set specifications.

There are nine generic categories of Performance Benchmarking:

- Customer service performance
- Product/service performance
- Core business process performance
- Support process and services performance
- Employee performance
- Supplier performance
- Technology performance
- New product/service development and innovation performance
- Cost performance

Benchmarking is usually an ongoing activity for organizations and is often part of competitive analyses or strategic-planning initiatives. Benchmarking often occurs concurrently with VOC work. VOC and benchmarking data are summarized in a QFD Matrix, which is used to prioritize measures.

Why use it?

- To identify ways to measure customer requirements
- To identify best-in-class measures and specifications that help determine performance targets
- To compare your performance to the performance of other companies

How do I do it?

1. **Review any information in your organization's database that could relate to performance.**
   - This information is often a good starting point for Performance Benchmarking.
2. **Examine other sources of information such as published studies, reports, and articles.**
   - Trade journals often describe companies that excel in particular areas. Conference proceedings or reports from awards ceremonies such as the Malcolm Baldrige National Quality Award are also good sources for information on companies noted for their best practices.
   - Benchmarking databases are also a good source of performance information.
3. **Analyze your research and incorporate your findings.**
   - Based on your research, you might:
     - Identify potential measures for customer needs.
     - Identify benchmark values to consider when setting targets for CTQ measures.

  - Identify how customers rank your organization's performance in relation to your competitors' performance on key measures.

2.3 Prioritize the CTQs

After completing substeps 2.1 and 2.2, you now have:

- A list of the most important customer segments.
- First-, second- and third-level needs, expressed in the customers' voice.
- A priority of needs at the appropriate level.
- Quality characteristics and measures related to these needs (i.e., the Voice of the Customer translated into design language).
- Targets and specification limits for the measures.

Now use the QFD Matrix to summarize the Voice of the Customer and your benchmarking information. The output of this tool will be the prioritized CTQs and will include measures, targets, and specifications.

What is it?

The QFD Matrix (also called the House of Quality) is a tool for summarizing the research data you gathered. The QFD Matrix uses customer needs and priorities, and summarizes any benchmarking work to allow you to understand key competitive measures and the relative performance of those measures among your competitors. Most of the work in developing a QFD Matrix involves compiling information. The information is then organized into various "rooms" that make up the matrix.

Why use it?

- To coordinate a vast amount of information and select the key measures that you will use in the rest of the design process

How do I do it?

To build a QFD Matrix:

1. **List the detailed VOC needs in the rows of the QFD Matrix and the measures for the CTQs in the matrix columns.**
2. **Fill in the cells of the matrix by asking, "If we design the process, product, or service to perform to the target specified for the measure, to what extent would we have met the need?"**
   - Use values of 1 for low correlation, 3 for medium correlation, and 9 for high correlation.

     Note: It is not necessary to fill all of the cells with a 1, 3, or 9; typically about one-third of the cells are filled.
   - An empty row indicates that a measure does not exist for the need; if the need is important, then you must define a measure for the need.
   - An empty column may indicate that the measure is not needed because it does not correspond to any need; it may also signal that a need was missed in the VOC. (Remember that customers often fail to mention Must Be needs.)
3. **Calculate the importance of each CTQ by matrix multiplication.**

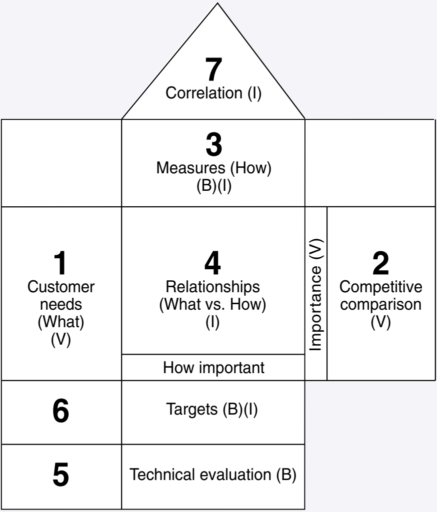
   Note: Matrix multiplication is described in Room 4 of "The Rooms of the QFD Matrix" section.

   Tip If your VOC research indicates that you have customer segments with very different needs, create a QFD Matrix for each segment. (Note: You may need to create different products or services for these segments.)

The importance rating calculated in step 3 is the output of the QFD exercise. Your objective in using the QFD Matrix is to find the smallest number of CTQs that meet the largest number of needs.

The Rooms of the QFD Matrix:

The QFD Matrix is divided into seven rooms.



(V) = Comes from VOC information
(B) = Comes from benchmarking information
(I) = Comes from internal expertise

Just like the rooms in a house, there are connections and relationships among the rooms.

Room	Contents	Where does this information come from?
1. Customer needs	Prioritized customer needs	The Voice of the Customer
2. Competitive comparison	Customer rating of key competitors' performance	The Voice of the Customer
3. Measures	Customer requirement measures (CTQs)	Benchmarking and the design team
4. Relationships	Relationship of CTQs to customer needs	Internal expertise and the design team
5. Technical evaluation	Actual performance of competitors on measures	Benchmarking
6. Targets	Performance required to meet CTQs/needs	Benchmarking and internal expertise
7. Correlation	Correlation between the measures	Benchmarking and internal expertise

Room 1 lists the key detailed customer needs identified by VOC research. These needs have been defined and prioritized by customers and are listed in the matrix in the customers' language.

> ***Tip*** Be sure to include all Must Be needs and key More is Better needs (from the Kano analysis) in the matrix. Also include Delighters if possible.

Room 2 graphically shows how customers perceive your organization's performance and at least two competitors' performance with regard to meeting the customer needs listed in Room 1. Information gathered from VOC research is used to establish how customers perceive the performance of your organization compared to market leaders.

Tip Use direct competitors who are market leaders or "excellence organizations" in your comparison. Select symbols to designate your organization's performance and the performance of the competitors you are comparing yourself with. Connect the symbols with lines to provide a better visual representation of customers' perceptions of the performance comparisons. Use a scale of 1 to 4 (with 4 representing how the "perfect" service or product performs) to rate performance.

You can easily collect the information for this room as you gather your VOC data. Use several sources of information to identify customers' perceptions of your competitors, including:

- Customer satisfaction surveys that collect information on customer ratings of both your organization and key competitors.
- Industry databases.
- Your own VOC research.

Room 3 represents the voice of your design team and lists the measures developed at the end of the VOC analysis. Ideas for measures can come from:

- The design team's work translating customer needs into CTQs (which include measures).
- Benchmarking information on how similar characteristics are measured.
- Measures currently in use for similar designs.

Note: Don't worry about having too many measures. There are often more measures than customer needs. (Each need could be addressed by multiple measures.) The QFD Matrix will help you eliminate unnecessary measures so that only the most important measures will be carried over into the next phase of the design process.

Note that some measures are intentionally vague. For example, the measure "percent information about completed order status accessible by customer" will be different depending on the design you choose and on the technology you use. (The particular technology is irrelevant; any solution should be able to meet the target specified for this measure.)

Tip Make sure the measures are measurable *during* design. For example, the measure "number of complaints" won't help you during design because it can only be measured after the product or service is in the market.

Indicate a preferred direction for the measures with arrows on the matrix (e.g., higher is better). To determine direction, ask:

- If we increase this measurement, will that help to achieve the customer need?
- If we reduce this measurement, will that help to achieve the customer need?
- If we hit the measurement target, will that help to achieve the customer need?

Allow adjustments of the measure's value as you make design decisions. Do not make the measure solution-dependent to prevent biasing yourself toward one outcome.

Room 4 summarizes your thinking about the relationship between potential measures and the customers' needs.

To determine these relationships, compare each measure (from Room 3) with each need (from Room 1) and ask, "If the design meets the target set for this measure, to what extent will we meet the customer need?" Use your experience, knowledge, and expertise to help you formulate these answers.

When recording the relationships in Room 4, document the assumptions that lead to your decisions about the relationships. You can return to this documentation later when you test parts of the design.

> ***Tip*** Use symbols or numbers (9, 3, or 1) in Room 4 to show the strength of the relationship between the measures and the needs. Use a double circle (or a 9) to show a strong relationship (a direct cause-and-effect). Use a single circle (or a 3) to indicate a moderate relationship. Use a triangle (or a 1) to signal a weak relationship. Indicate that no relationship exists by leaving the space where the need and measure intersect blank.

	◎	○	△	
	Strong	Moderate	Weak	None
Weight	**9**	**3**	**1**	**0**

Calculate the importance of each measure by multiplying the relationship weight (9, 3, or 1) by the importance that customers assigned to the need from the column marked "Importance" in the matrix. (Remember that customers provided these importance ratings when they prioritized or ranked their needs.) Then add the scores within the column and record the scores in the "How important" row at the bottom of the matrix. Use these scores in your discussion to check your thinking and to help identify the key measures that drive overall customer satisfaction. These key measures become the most important criteria against which to evaluate the design.

> ***Caution:*** Do not let the results of the calculations by themselves make the decision on prioritizing the measures. You could have a measure with a relatively low total number because it correlates with only one need. However, if that need is a Must Be need, the measure is important to keep.

Room 5 summarizes the technical benchmarking data that compares your company to your competitors with respect to performance on key measures/design requirements. Again, use symbols to represent your organization and your competitors, just as you did in Room 2. Connect the symbols using lines and rate the comparison on a scale of 1 to 5 (with 5 representing "better" in this room).

Benchmarking your own processes, products, or services and the processes, products, or services of others against key design measures that you have identified will help you to define the current level of performance. It also helps you to answer the questions:

- Have you defined the right measures to predict customer satisfaction?
- Does the process, product, or service have a perception problem (i.e., a difference in Room 2), as opposed to a technical problem (a difference in Room 5)?

Room 6 summarizes the targets established for the measures/CTQs.

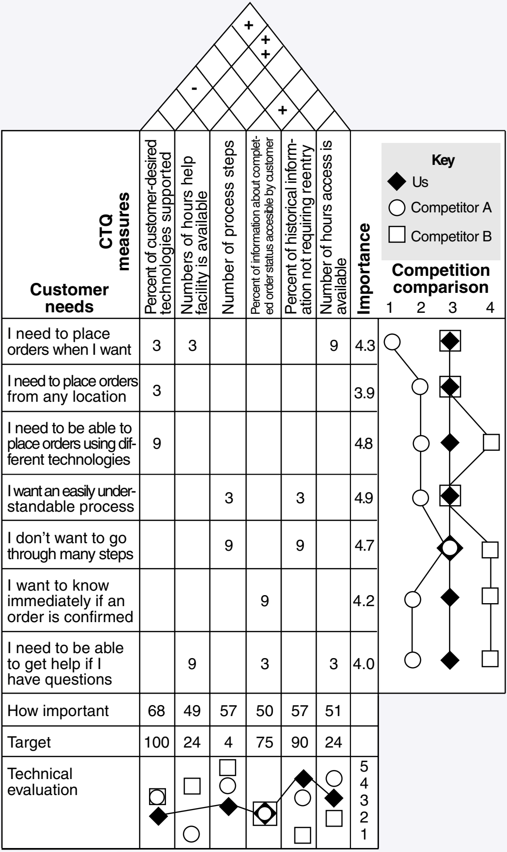
You already set the target values for the design requirements in step 2.2.2. Now summarize the targets in Room 6 by examining the data gathered throughout the process and determine what you are going to do with respect to this process, product, or service.

Room 7 (the "roof") summarizes the relationships between the measures. Determine if a positive or negative relationship between measures exists by asking, "If we design to meet CTQ 1, to what extent do we satisfy or what will the effect be on CTQ 2?" If CTQ 2 will also move toward its target, then there is a positive effect. If CTQ 2 is not affected, then the effect is neutral. If CTQ 2 moves away from its target, then the effect is negative.

Use symbols (such as + and -) to represent the relationships and then evaluate the outcome. Positive relationships indicate synergy and negative relationships may indicate conflicts.

Tip The design task becomes easier if you have a lot of positives in the roof of the matrix. A positive relationship indicates that if one aspect of the design is improved, other aspects will be improved as well. If you have a lot of negatives in the roof of the matrix, then you have design contentions; improving one aspect of the design may lead to problems in other aspects. If you have too many design contentions, you may have to develop more creative designs that transcend the contentions, or carefully evaluate trade-off decisions that you may have to make.

A Sample QFD Matrix



CTQ measures Customer needs	Percent of customer-desired technologies supported	Numbers of hours help facility is available	Number of process steps	Percent of information about completed order status accesible by customer	Percent of historical information not requiring reentry	Number of hours access is available	Importance
I need to place orders when I want	3	3				9	4.3
I need to place orders from any location	3						3.9
I need to be able to place orders using different technologies	9						4.8
I want an easily understandable process			3		3		4.9
I don't want to go through many steps			9		9		4.7
I want to know immediately if an order is confirmed				9			4.2
I need to be able to get help if I have questions		9		3		3	4.0
How important	68	49	57	50	57	51	
Target	100	24	4	75	90	24	
Technical evaluation							

Analyzing QFD

Use QFD analysis in the Measure step to help you see all of the information that you have gathered at once and to guide a systematic discussion of the measures as you prioritize the design requirements of the CTQs. If the design has only a few measures, you may not need to use the QFD Matrix because you may not need to prioritize the measures. However, if you have a lot of measures, you need to select a few important ones to use in the next design step as you assess potential concepts.

Use QFD analysis to also help you recognize opportunities to leverage design efforts and identify any trade-offs.

Ultimately, the QFD Matrix should serve as a validation for your business instincts. The QFD Matrix scores are simply the inputs to discussions. Your team's expertise and knowledge of the customer needs will guide your decisions.

If the QFD exercise produces results that do not match your intuition, ask the following questions before accepting the results:

- *Are all of the needs at the same level?* If needs are at various levels of detail, there may be multiple statements describing the lower level needs and a single statement describing the higher level need. This will cause the CTQs describing the lower level needs to appear to be more important than those describing the higher level need.
- *Are there multiple measurements when one might suffice?* Multiple measures correlated with the same need may result in a narrow set of design specifications concentrating on just one aspect of the design.

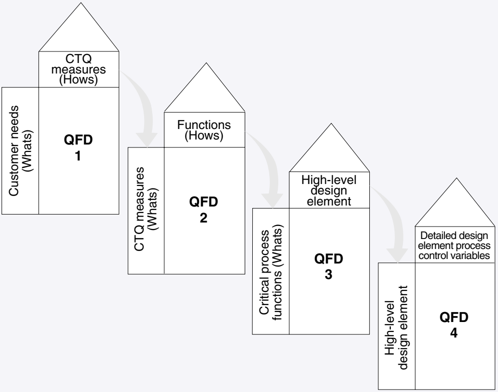
- *Are there any empty rows?* Empty rows indicate that the measure set is not complete.
- *Are there any empty columns?* Empty columns indicate redundant measurements or a Must Be need that is not represented in the matrix.
- *Is the matrix in Room 4 diagonal?* A diagonal pattern indicates that you may have defined the measures too narrowly.
- *Is there a mismatch between the customer evaluation data in Room 2 and the technical benchmarks in Room 5?* A discrepancy may indicate a mismatch between perception and reality.

Tip In some cases, the information from one QFD Matrix may be sufficient to proceed with the preliminary design. In other instances, you can use QFD analysis to further deploy the customer needs into design specifications via additional QFD Matrices. This is particularly true for products that are assembled from parts.

To begin a second QFD Matrix, place the measures from Room 3 of the first Matrix as the "whats" in Room 1 in the second Matrix. Then use your judgment to determine "how" to accomplish the measures. Identify the functions needed in the design and put them in Room 3 of the second QFD Matrix. Then use the same process you used previously to complete the matrix.

As shown on the following page, you can develop several matrices to achieve a very detailed understanding of the variables to control to ensure that you satisfy the customer needs.

Additional QFD Matrices to Deploy Further Needs



In the Measure step, the work with the QFD Matrix ends with the selection of key measures for the design and an understanding of the relationships between those measures. Now revisit your Charter and, based on current knowledge, reassess the project's scope and risks.

2.4 Reassess the Risk

After prioritizing the CTQs, reassess the risks associated with the project by asking:

- How difficult will it be to meet all of the target values of the most important CTQs?
- Do we need to adopt a phased approach to meet the target?

- What are the risks associated with not meeting the CTQs now?
- What are the risks associated with dropping some of the less important CTQs from consideration?

How do I do it?

1. **List the CTQs dropped from consideration (through your use of the QFD Matrix) and describe the associated risks.**
    - Ensure that the risks are acceptable and justify dropping the CTQs.
2. **List the CTQs whose target performance values you cannot meet now and describe the associated risks.**
3. **Determine whether you can meet the risks identified above by adopting a phased strategy.**
    - If you cannot meet all of the critical performance requirements immediately, consider a phased approach in which you create a base product or service along with a platform on which to build further enhancements.

    Caution: While an opportunity to delight customers through high-quality enhancements is possible in a phased approach, there is also a risk of dissatisfying customers who are left waiting for an enhancement.

Use the CTQ Risk Matrix and/or the Multistage Plan to support risk analysis.

CTQ Risk Matrix

What is it?

The CTQ Risk Matrix shows the risk associated with not meeting the target performance requirements and/or with dropping some of the CTQs. The CTQ Risk Matrix should consider risk along three dimensions:

1. **Inclusion: Will we include the CTQ further in the design process?**
2. **Complexity: Are the technology requirements too complex to develop all at once?**
3. **Reach: Will we meet the CTQ requirements for all customer segments simultaneously?**

Each of these dimensions involves risk and may result in customer dissatisfaction. Even if you can design the service to meet the CTQs, it may not be technically feasible to meet all of the requirements immediately. Similarly, it may not be possible to deliver the service to all market segments at the same time.

Why use it?

To identify and plan for risks

How do I do it?

1. **List the CTQ measures in the left-hand column of a matrix.**
2. **Determine if there is a design specification for the measure and list this information as a "Yes" or "No."**

3. **List the target performance value for each CTQ.**
4. **Qualitatively estimate the gap between the desired target levels and the current best-in-class benchmark or target needed, based on VOC data. List this information as "the ability to meet the target with the base platform."**
    - The first design phase or base platform represents the first version of the design that you will implement.
    - If the gap is very large, it may not be possible to close the gap in the first design implementation.
5. **List an estimate of the risk associated with not meeting the target.**
6. **Describe the risk mitigation plan for each CTQ.**
7. **Develop a phased approach if you cannot meet all included CTQs immediately.**
    - Each phase is a sequential time period for implementing the design. Describe the design phases using a Multistage Plan.

A Sample CTQ Risk Matrix

CTQ measure	Design specification	Target perfor-mance value	Ability to meet target with base platform	Associated risk	Risk mitigation plan
Percent of customer-desired technologies supported	Yes	100%	Medium	High–signficant impact on customer satisfaction	Accelerate ability to support all technologies
Percent of historical information not requiring reentry of data	Yes	75%	Low	High–key contributor to customer satisfaction	Include in extension platform
Number of hours online help facility is available	No	N/A	N/A	Low–met by overall accessibility requirement	None
Percent of information about historical orders accessible	No	60%	Depends on other CTQs	Medium–may not be completely met by other CTQs	Revisit after concept selection is complete

Multistage Plan

What is it?

The Multistage Plan specifies the phases you will use to implement the process, product, or service design. The cells of the Multistage Plan matrix describe the features of the design in each time period and for each customer segment. The multiple phases of the design are often indicated by color-coding.

Why use it?

- To create phased plans to deal with risk
- To keep the scope of the project contained so that it is manageable
- To ensure that the first generation of a design will get to the market within the specified time window
- To provide a market presence for the organization while implementing the later stages of a design
- To learn from customer reaction to the first phase of the design while implementing the later phases of the design

How do I do it?

1. **Create a matrix with the names of the design phases in the left-hand column of the matrix and the customer market segments for the design along the top row of the matrix.**
2. **Fill in the cells of the matrix with the features of the design that could apply to each market segment in the specified phase.**

- The complexity of the implemented design may vary for each phase and customer segment. Use the following definitions to describe the design complexity:
  - The *Base Platform* is the base design. Typically the least complex design, it may not meet the performance targets for some CTQs.
  - The *Platform Extensions* are the more-complex extensions to the base design.
  - A *New Platform* is a completely different design, which is often out-of-scope for the current project.

  Note that the base platform and its extensions reflect differences in the complexity of the design. It is not necessary for every customer segment to have a base platform implemented first, followed by the platform extensions; for some critical segments, you may need to implement a design that includes the platform extensions in the first phase to maintain a competitive advantage.

Tip Keep the feature descriptions general and free of specific technologies. You will select the specific technologies for the design later in the concept design stage.

In the example on the next page, the implementations for the domestic Fortune 500 and medium/small business market segments proceed from the base platform through two extensions. The first phase of the design simplifies processes and provides unlimited access and help facilities, but does not support all ordering channels, nor does it support historical ordering data for all market segments. Subsequent phases of the design enhance the basic platform and increase the number of channels supported, as well as the amount of historical data stored in the system. The design is out-of-scope for the international customer segment because satisfying that segment would involve a new platform.

A Sample Multistage Plan

Market segment Design description	Domestic Fortune 500	Domestic medium/small business	International customers
Phase 1 (4Q '00)	Streamlined process: Unlimited access and help facilities; Most channels supported; Limited history data	Streamlined process: Unlimited access and help facilities; Most channels supported; Limited history data	New platform TBD; Out of scope
Phase 2 (2Q '01)	Phase 1 platform with all requested channels supported	Phase 1 platform with all requested channels supported	New platform TBD; Out of scope
Phase 3 (4Q '01)	Phase 2 platform with all requested history data	Phase 2 platform with all requested history data	New platform TBD; Out of scope

2.5 Hold a Tollgate Review

Note: For general information on tollgate reviews, see section 1.5 in the Define step.

The tollgate review for the Measure step focuses on:

- The customer segmentation strategy.
- The top 10–15 customer needs.
- The top 8–10 CTQs and targets.
- Summarized benchmark information.
- The Multistage Plan.

This tollgate review can lead you to:

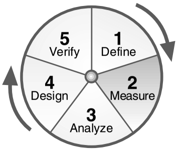
- Proceed to the Analyze step.
- Redo parts of the Measure step and hold another review.
- Stop the project.

How do I do it?

1. **Review the Tollgate Review Form used at the end of the Define step.**
2. **Revise and answer the specific questions that describe what was done in this step and what you will need to do in the Analyze step.**

   Tip Remember to update your Storyboard before proceeding to the Analyze step.

The Measure Tollgate Review Form



Measure:
Prioritize the CTQs
from the VOC

Deliverables:

- ☐ Customer segmentation and research
- ☐ Prioritized CTQs
- ☐ Updated Storyboard presentation
- ☐ Updated project plan

- Who are the customers of the process, product, or service? Of these, who are the most important customers?
- Do all customers have the same needs? If not, what are the different needs of the different segments?
- What data was collected and why? How did you collect the data?
- What are the prioritized CTQs? How did you determine this?
- What performance targets must the design meet to satisfy customers?
- How does your competition meet your customers' needs?
- What limitations or barriers have you encountered?
- Review your project plan: are you on track?
- What are your key learnings from the Measure step?
- What are your next steps?

Analyze
Concepts

Why do it?

To generate a range of concepts (i.e., ideas or solutions for the process, product, or service being designed), then evaluate and select the concept that best meets the CTQs within budget and resource constraints.

Tools used in this step:

- The QFD Matrix
- Creativity tools:
  - Brainstorming and Brainwriting
  - Analogies
  - Assumption Busting
  - The Morphological Box
- The Pugh Matrix
- Tollgate Review Forms

Outputs of this step:

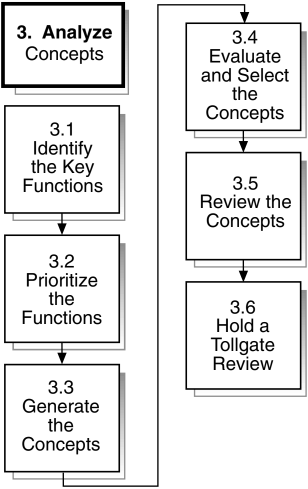
- A selected concept (or concepts) for further analysis and design
- A tollgate review and updated Storyboard

Key questions answered in this step:

- What are the most important functions or processes that must be designed to meet the CTQs?

- What are the key inputs and outputs of each process?
- Which functions or processes require innovative new designs to maintain a competitive advantage?
- What are the possible design alternatives for each function or process?
- What criteria should we use to evaluate these design alternatives?
- How do we collect information on these criteria to help us effectively evaluate these designs?
- How does the selected concept affect the features included in the base design and platform extensions?

How do I do it?



3.1 Identify the Key Functions

1. **Express the process, product, or service to be designed as a "black box" with inputs and outputs.**

2. **Determine the functions or activities that have to be performed in the black box.**

   - The designed process, product, or service must perform certain activities (called functions) to provide value to the customer. As you design the process, product, or service, describe these functions in words that do not depend upon a specific technology, to prevent biasing your design toward that technology. For example, as you describe a process for cleaning clothes, describe the function as "remove dirt from clothes" rather than "wash clothes" because the term "wash" implies a specific technology. (The design must be able to perform the functions no matter what technology you use for the design.)

   - Express the functions in the most basic format, as a verb/noun pair.

   Caution: The wording of the functions is extremely important. Deciding too quickly on wording that implies specific technology and/or design decisions impedes the creative innovative process.

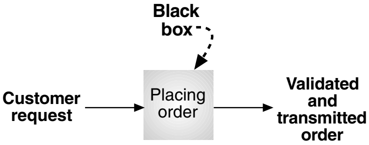
3. **Draw a block diagram showing the interactions between functions.**

   - Make sure that the outputs of the preceding functions lead into the inputs of the following functions and that no disconnected functions exist. Be aware that all functions may not be linearly connected.

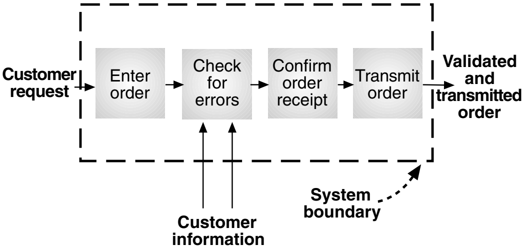
4. **Draw a system boundary to define the limits for the process, product, or service to be designed.**

Tip For process or service design projects, the functions are identical to the process steps so the function diagram is simply a high-level process flowchart.

To identify the functions in an order placement process, for example, first express the process as a black box with inputs and outputs.



Next, use technology-independent words (such as "enter," "check," "confirm," and "transmit") to describe the functions or tasks to be performed in the black box. Express these functions as simply as possible. Show the interactions between the functions using arrows, and draw a dashed line to show the system boundary that defines the limits for the design.



3.2 Prioritize the Functions

1. **After identifying all of the key functions, identify those that are critical to the design to help you determine:**
   - Which functions need the most resources.
   - Which functions need innovative designs.
   - Which functions can use existing designs.
   - Which functions you can copy from competitors or industry standards.
2. **Prioritize the critical functions by mapping them to the CTQs using the QFD Matrix.**
   - Recall from the Measure step that the first QFD Matrix (QFD 1) uses the most important customer needs to prioritize the CTQs.

     A second QFD Matrix (QFD 2) will relate the CTQs prioritized in QFD 1 to the functions identified for the new design, to focus the design effort on the functions that will have the greatest impact. Also, with an understanding of the relationships between the CTQs and the functions, you can establish clear requirements for the critical functions to aid in developing more-detailed designs in the latter steps of the DMADV process.

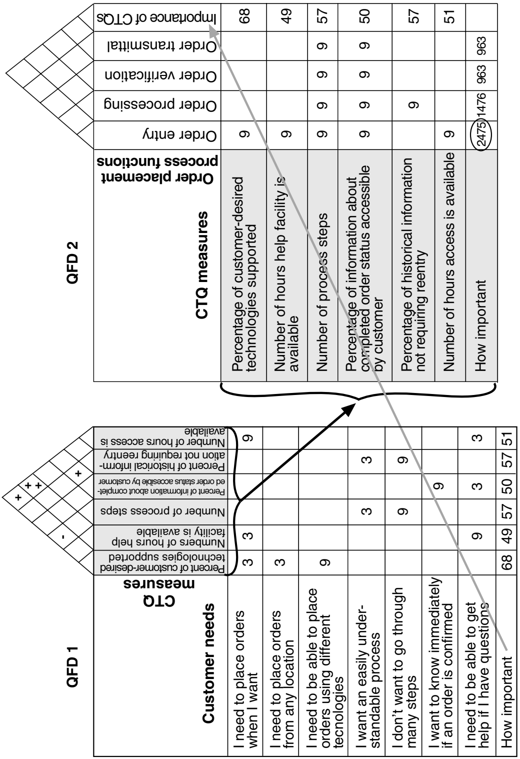
   a) Place the CTQ measures from QFD 1 into Room 1 of QFD 2. Place the key functions you identified in substep 3.1 into Room 3 of QFD 2. Record the relationships between these functions and measures in the cells of Room 4 of QFD 2 by asking, "If we design this particular function correctly, what impact does it have on our ability to meet the CTQs?" Decide how strongly each function impacts each CTQ and use the 9, 3, 1 scale introduced in the Measure step to represent this relationship.

Caution: Be sure to ask the specific question, "If we design this particular function correctly, what impact does it have on our ability to meet the CTQs?" Reversing the question will skew the results.

b) Calculate the importance scores for each function by multiplying the importance ratings for the CTQs (from the "How important" row in QFD 1) by the 9, 3, 1 correlation rating you determined above for each cell, and then adding the cell scores in each column to calculate the importance score for each function. Record these scores in the "How important" row of Room 4 in QFD 2.

Tip Calculating the importance scores often results in large numbers that get even larger if you use these importance scores in further QFD Matrices. To reduce the size of these numbers, rescale the CTQ importance numbers by assigning a value of five to the most important CTQ and adjusting the other values accordingly.

Mapping the CTQs to the Functions of the Order Placement Process



QFD 1

Customer needs / CTQ measures	Percent of customer-desired technologies supported	Numbers of hours help facility is available	Number of process steps	Percent of information about completed order status accesible by customer	Percent of historical information not requiring reentry	Number of hours access is available
I need to place orders when I want	3	3				9
I need to place orders from any location	3					
I need to be able to place orders using different tecnologies	9					
I want an easily understandable process			3		3	
I don't want to go through many steps			9		9	
I want to know immediately if an order is confirmed				9		
I need to be able to get help if I have questions		9		3		3
How important	68	49	57	50	57	51

QFD 2

CTQ measures / Order placement process functions	Order entry	Order processing	Order verification	Order transmittal	Importance of CTQs
Percentage of customer-desired technologies supported	9				68
Number of hours help facility is available	9				49
Number of process steps	9	9	9	9	57
Percentage of information about completed order status accessible by customer	9	9	9	9	50
Percentage of historical information not requiring reentry		9			57
Number of hours access is available	9				51
How important	2475	1476	963	963	

The output of the QFD 2 Matrix is a prioritization of functions. This prioritization helps you identify the parts of the design that need to be innovative and the parts that can be supported by existing or "also-ran" technology. In our order placement process example, it is clear from the graphic above that order entry is the most important function and any process innovations should focus on this step of the order placement process.

> ***Tip*** Examine empty rows or columns in the QFD Matrix closely. A CTQ with no associated function (an empty row) may indicate that you did not identify all of the necessary functions. A function with no associated CTQ (an empty column) could be an example of a non-value-added function or a redundant function.

3. **After prioritizing the critical functions, review your Multistage Plan.**
   - Ask:
     - How many critical functions have been considered in the first phase of the design?
     - Are any critical functions not considered until later phases? What are the risk implications of this delay?
     - Have we left any functions out of the Multistage Plan? How should we include these functions?
     - Is it necessary to revise the Multistage Plan to adjust the platform descriptions for each phase?

3.3 Generate the Concepts

Concept generation involves creating as many alternative ideas or solutions for the process, product, or service as possible to meet customer requirements.

Tip Concept design is just one step toward building a process, product, or service. Proceeding step-by-step through the design process from concept to high-level to detailed design ensures that expensive, risky decisions are not made until you analyze the design in detail and there is a degree of confidence that the selected design will perform as required by the CTQs.

There are two approaches for generating concepts: *bottom up* and *top down*. The bottom-up approach generates concepts *function by function*. The top-down approach generates concepts *across* functions.

Tip The bottom-up approach works better for redesigning pieces of an existing process, product, or service, while the top-down approach is especially effective for new designs. However, many designs will incorporate some new design and some existing design together in a new process (i.e., an existing phone ordering process may need to utilize new technology, so part of the process will need a new design). If so, you may have to use a combination of approaches. For the part of the design that is a redesign, you can use a bottom-up approach. For the part of the design that is new, you should work top down. Ultimately, you will have to combine these two approaches as you complete your work.

When generating concepts using either a bottom-up or top-down approach, make sure that you include all of the following applicable elements in the concept description:

- Product features
- Information systems
- Human systems
- All key processes

- Materials
- Equipment
- Facilities

Tip Do not worry too much about using the exact categories listed above. Use this list only as a guide to ensure that you have not missed anything in the process of generating concepts.

To generate concepts in a *bottom-up approach*:

1. **Determine whether you need to create a new design for each function or whether an existing design is adequate.**
2. **For each function that needs a new design, generate as many verbal descriptions or drawings of alternate solutions as possible.**
3. **Eliminate or combine impractical alternatives for each function until no more than 3–5 viable options for each function remain.**
    - Note that these alternatives are not concepts; concepts involve combining the alternatives across functions.
4. **Assemble concepts by determining which alternatives will combine well with alternatives of other functions, and then linking compatible alternatives together to create concepts or design solutions.**
5. **Select 3–5 concepts for further analysis.**

    Note: The most common tool to generate concepts in a bottom-up approach is the Morphological Box, which is explained in greater detail later in this chapter.

A bottom-up approach (using a Morphological Box) for our order placement process will generate alternatives for each key function identified in the black box from substep 3.1, as shown on the next page.

A Bottom-Up Concept Generation Example

Function	Alternative 1	Alternative 2
Enter order	Over the telephone using an Interactive Voice Response (IVR) system ○	Over the internet using a secure browser ★
Check for errors	Manual check using a live agent	○ System check for ★ completed fields
Confirm order receipt	Follow-up telephone call ○	Email ★
Transmit order	Order carried to delivery department by agent	Order information ★ accessed over intranet ○

○ Concept 1 ★ Concept 2

You could conceivably assemble sixteen different concepts (2 x 2 x 2 x 2 = 16) by combining these alternatives. After developing the sixteen concepts, you would then select 3–5 concepts for further study. The concepts you select must be feasible and, based on informed judgment, deemed worthy of further study.

To generate concepts in a *top-down approach*:

1. **Develop concept ideas at a systems level (across all functions) to show how you could satisfy customer needs.**
    - Envision an entire system that will satisfy the requirements of your customers.
2. **Write verbal descriptions of these concepts or draw the concepts as pictures.**
3. **Map the verbal descriptions or drawings to the necessary functions.**
4. **Ensure you have not missed any critical functions.**
5. **Mark the functions that need a new design.**

A top-down approach for our order placement process could generate the following three concept examples:

Top-Down Concept Generation Examples

Concept 1: **Automated telephone ordering**

Customers can call the order processing center twenty-four hours a day and can place their order without human intervention. Confirmation is immediately available upon completion of the ordering steps. Customers can obtain verbal information about any ordering questions by pushing the appropriate telephone buttons. Customers can also fax or mail in their orders to the order processing center, but confirmation is not immediately available. Customers seeking confirmation for such orders or information about previous orders can call the twenty-four-hour order processing center. All questions are addressed by this single center. Orders are stored in a database accessible by the order management department.

Concept 2: **Internet ordering with videoconferencing support**

Customers have a virtual account that they can access over the internet. The virtual account provides information about current and past orders and also provides access to questions about ordering. For additional questions, videoconferencing with a live agent is available at an additional charge; for customers who do not have videoconferencing capabilities, regular telephone communication is available and the customer's screen is visible to the agent. Customers can call, fax, or mail non-internet orders to an order processing center twenty-four hours a day. Confirmation is available immediately on orders called in, but not on orders written or faxed. Orders are stored in an intranet database accessible by the order management department.

Concept 3: **Point-of-sale connection to an order manager**

An order manager is linked to the customer's point-of-sale system and an order is automatically placed based on store stock levels. Confirmation of orders is provided automatically to customers when the order is placed. Overrides of automatic orders or questions about previous orders are called into the order processing center. Fax and written orders are not supported.

Both the top-down and bottom-up approach require some creative thinking in the actual generation of concepts. Begin with benchmarking techniques that study designs in competing and noncompeting businesses and then use creative idea-generation techniques that focus on analogies, connections, extrapolations, and creative visualization, to develop new ideas.

The skills you will need to creatively generate ideas include domain relevant skills (knowledge of the facts, technical skills, and motor skills), creativity relevant skills (experience with creativity tools and a disciplined work style), and task motivation. Typically, the creativity relevant skills provide an extra "push" to a person or team possessing domain relevant skills. Creativity alone cannot substitute for a lack of subject matter knowledge or motivation.

> **Note:** In the Measure step, you may have benchmarked for measures and technical comparisons. In the Analyze step, you will benchmark to understand *how* world-class organizations provide products or services. The best practices of other organizations provide ideas for concepts at this stage of design.

There are several kinds of creativity tools, including:

- Association Methods: Tools such as Brainstorming and Brainwriting that build upon what you already know.
- Creative Confrontation Methods: Tools such as Analogies that challenge what you think you know.
- Assumption Busting Methods: Tools that challenge the assumptions or perspectives you currently have.
- Analytic Systematic Methods: Tools such as the Morphological Box that provide systematic guidance in constructing innovative concepts.

Note: For more information on creativity tools, see *Product Design: Fundamentals and Methods* by N.J.M. Roozenburg , J. Eekels, and N.F.M. Roozenburg, Wiley, 1996, and *The Creativity Tools Memory Jogger*™ by Michael Brassard and Diane Ritter, GOAL/QPC, 1999.

Brainstorming

What is it?

Brainstorming allows team members to build on each other's creativity while staying focused on their joint mission. It encourages open thinking when a team is stuck in "the same old way of thinking," gets all team members involved, and prevents a few people from dominating the whole group.

There are two major methods for brainstorming: *Structured Brainstorming* in which each team member gives an idea in turn, and *Unstructured Brainstorming* in which team members give ideas as they come to mind.

Why use it?

To allow a team to creatively and efficiently generate a high volume of ideas on any topic by creating a process that is free of criticism and judgment

How do I do it?

1. **Agree on a central Brainstorming question and write it down for everyone to see.**
   - Be sure that everyone understands the question, issue, or problem. Check this understanding by asking one or two members to paraphrase it before recording it on a flipchart or board.

2. **Have each team member, in turn, give an idea.**
   - Allow a team member to pass at any time. (While the rotation process encourages full participation, it may also heighten anxiety for inexperienced or shy team members.)

   Tip The Unstructured Brainstorming process is the same as the Structured method except that everyone gives ideas at any time, rather than in turns. There is no need to "pass" because ideas are not solicited in turn.

   Caution: Do not allow criticism of any idea. Criticism impedes the creative process and may prevent team members from sharing their ideas.

3. **As you generate ideas, write each one in large, visible letters on a flipchart or other writing surface.**
   - Make sure you record every idea in the exact words of the speaker; don't interpret his or her meaning. To ensure that you have captured the speaker's exact meaning, ask the speaker if the idea has been worded accurately.

4. **Continue to generate ideas until each person passes (or discussion stops, if you are using the Unstructured method), indicating that the ideas have been exhausted.**
   - Keep the process moving and relatively short; 5–20-minute sessions work well, depending on how complex the topic is.

   Note: Brainstorming to generate concepts may require more than twenty minutes and/or more than one Brainstorming session.

5. Review the written list of ideas for clarity and discard any duplicates.

- Discard an idea only if it is truly a duplicate. It is often important to preserve subtle differences that are revealed in slightly different wordings.

Tip For effective brainstorming:

- Allow individuals to complete their thoughts.
- Build on existing ideas.
- Be brief when stating an idea.
- Organize, categorize, and evaluate only after the session.
- Strive for quantity.
- Don't criticize ideas or make judgments as ideas are being offered.
- Don't dominate the session.

An alternative way to stimulate creative team thinking is through Brainwriting. There are two approaches to Brainwriting: the 6-3-5 Method and the Brainwriting Pool.

In the 6-3-5 Method, six participants each write three ideas on a separate form. The participants pass the forms among themselves five times, adding new ideas to the forms.

In the Brainwriting Pool, 5–8 participants each jot ideas on a sheet of paper in silence. Participants who have run out of ideas place their sheets in the middle of the table, pick up another member's sheet, and add ideas to it. After 20–30 minutes, the ideas are collected and evaluated.

Analogies

What is it?

An analogy uses a random word, object, or situation to make unusual connections to a problem or design challenge. It provides a virtually unlimited supply of inspiration for breakthrough thinking, enables team members to create a new focus point for their thinking, and re-energizes a Brainstorming process that has reached a lull.

Why use it?

To stimulate fresh perspectives and new solutions by using random words, pictures, or situations that are unrelated to the original problem.

How do I do it?

1. **Start with a familiar situation and make it strange by deliberately altering or undermining it in some way.**
   - Alter it by using analogies such as:
     - A personal analogy (i.e., put yourself in the problem).
     - A direct analogy (i.e., seek an comparable problem from another discipline).
     - A symbolic analogy (i.e., explain the problem using symbols or metaphors).
     - An ideal analogy (i.e., imagine an ideal situation).
2. **Adjust these analogies to fit the original problem.**
   - Apply the thinking associated with the analogy to the original problem to stimulate new ways to solve the problem.

Assumption Busting

What is it?

Assumption Busting challenges the conventional assumptions about a problem or issue.

Why use it?

To escape the self-imposed constraints that traditional assumptions often create

How do I do it?

1. **State the problem or design challenge.**
2. **Write down as many existing assumptions about the problem or design challenge as you can think of.**
3. **Challenge the assumption by:**
    - a) **Reversing the assumption.** For example, if you currently assume that all transactions require approval from a department head, assume that such approval will no longer be required.
    - b) **Modifying the assumption to make it better or easier to deal with**. Change a name, time frame, or location. For example, assume that supervisors, rather than department heads, need to approve transactions.
    - c) **Varying your perspective**. Try viewing the assumptions from the perspective of another person, work group, or organization and describe the problem from their perspective. Write down new ideas that emerge from looking at things this way.

Morphological Box

What is it?

A Morphological Box helps identify all of the parts of the problem that you must address to create a successful solution. It displays options for solving each essential part of the problem, and helps you evaluate several solutions at one time.

Why use it?

To provide a more systematic means of generating solutions

How do I do it?

1. Assemble a knowledgeable team.

- Unlike some of the other creativity tools, the Morphological Box requires experts in the content area being discussed. These experts can join the team as needed or become permanent members.

2. Define the parameters necessary for any solution to the problem.

- A parameter is a characteristic that a solution must possess for it to be effective. A good parameter must:
  - Be independent from the other parameters.
  - Describe a complete solution when combined with the other parameters.
  - Be valid for all potential solutions.
  - Represent an essential characteristic of an effective solution.

Tip While there is no absolute rule for the number of parameters you can use, you should work from a list of six parameters or fewer when starting out. If you have difficulty identifying the parameters, create an Affinity Diagram for the design challenge and use the headers developed in the Affinity Diagram as the parameters.

3. **Place the selected parameters in the left-hand column of a matrix. Label the successive columns of the matrix as "Alternative 1," "Alternative 2," and so on.**

Tip You will have a good list of parameters when you can "add" all of the parameters together to get a complete solution.

4. **Generate options (alternatives) for each parameter.**

- Brainstorm a minimum of two options for each parameter.

Caution: More options are not always better. Generate options that draw on both your current knowledge and your imagination.

5. **Build alternative solutions by linking different options.**

- Within each parameter (row), select at least one option. You can make this selection randomly (to maximize creative combinations) or systematically (to intentionally focus on specific combinations).

Note: Generally, only one option is selected within a parameter. Select more than one option only when it will lead to more-interesting combinations. Don't choose more options simply to avoid making a choice.

- Clearly mark the selected option(s) within the first parameter and draw a line to the selected option(s) in the next parameter. Continue to repeat this process until you connect all selected options by a line.
- Develop alternative combinations of options by repeating the marking and connecting process. Distinguish between the combinations of options by using differently marked points (e.g., boxes, triangles, circles) and connecting lines (e.g., solid, dotted, dashed). Be creative but also be clear.

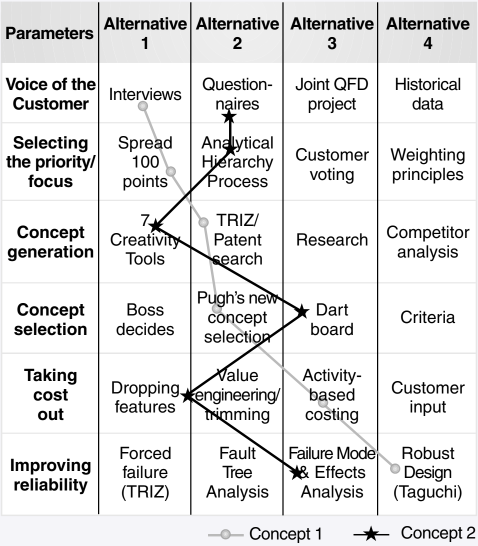
6. Analyze the alternative solutions and select the best one(s).

Methods to evaluate and analyze the combinations include:

- Intuitive: Selecting those combinations of options that "feel" the most promising or interesting. (This works best with six parameters or fewer.)
- Optimization: Selecting the "best" option within each parameter and then combining these options to produce the one "best" combination across all parameters. Understand that the resulting combination may not actually work and may require substituting some options with the next best option to create a viable solution.
- Sequential: Considering the two, three, or four most important parameters and their options, then selecting options for each of the remaining parameters that look like the best combination with the options chosen for the most important parameters.

Tip Even a modest-sized Morphological Box can generate a large number of different combinations. (To determine the number of possible combinations, multiply the number of options in the first parameter by the number of options in the second parameter, by the number in the third parameter, and so on, to the last parameter.) Clearly, the sheer number of possible combinations that a Morphological Box can create demonstrates a need to narrow down the number of combinations for evaluation.

A Sample Morphological Box

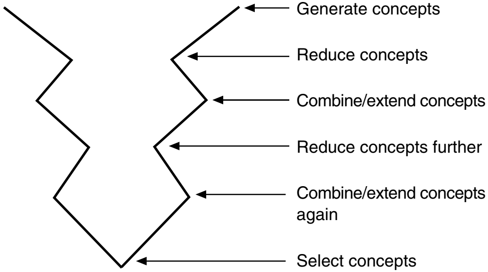


Parameters	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Voice of the Customer	Interviews	Questionnaires	Joint QFD project	Historical data
Selecting the priority/ focus	Spread 100 points	Analytical Hierarchy Process	Customer voting	Weighting principles
Concept generation	7 Creativity Tools	TRIZ/ Patent search	Research	Competitor analysis
Concept selection	Boss decides	Pugh's new concept selection	Dart board	Criteria
Taking cost out	Dropping features	Value engineering/ trimming	Activity-based costing	Customer input
Improving reliability	Forced failure (TRIZ)	Fault Tree Analysis	Failure Mode & Effects Analysis	Robust Design (Taguchi)

3.4 Evaluate and Select the Concepts

In the previous substep, you generated a number of solutions or concepts for your design. Now you must evaluate these options and select one or two concepts for further development.

One way to consolidate the ideas you generated is through controlled convergence. Controlled convergence is a process that successively generates and reduces concepts until a satisfactory concept is reached. Each round of the controlled convergence process reduces the number of remaining concepts until only one or two remain.



Controlled Convergence

Tip As you proceed through controlled convergence, do not generate completely new concepts to add to the existing set. Instead, combine and extend what you have already created to produce a smaller set of superior concepts.

You can also use a Pugh Matrix to help you evaluate and select design concepts.

Pugh Matrix

What is it?

The Pugh Matrix helps select the best design concept(s) from among alternatives.

Why use it?

To produce more-innovative and robust designs by comparing design concepts and integrating the best features from various concepts into "super concepts"

How do I do it?

1. **Determine a baseline for the project.**
   - For redesign projects, use the current process, product, or service as the baseline. For new designs, select the "middle of the road" (i.e., neither too manual nor requiring extremely advanced technology) as a baseline.
2. **Place the concepts as the headers in the columns of a matrix and list the evaluation criteria in the matrix rows.**
   - Use customer CTQs from the QFD Matrix as your evaluation criteria and add other business criteria such as cost, ease of implementation, and technological feasibility.
3. **Compare each concept to the baseline on each criterion.**
   - If the concept is better than the baseline on the criterion, assign a "+"; if it is worse, assign a "-"; if it is the same, assign an "S."

4. **Count the number of positives, negatives, and "sames" for each concept and record them in the matrix.**
5. **Calculate the weighted sums for the positives by adding together the importance ratings for each criterion assigned a "+". Calculate the weighted sums of the negatives by adding together the importance ratings for each criterion assigned a "-". Record these sums in the matrix.**
   - Use the importance ratings for the CTQs from the QFD 1 Matrix. If necessary, rescale these importance ratings for convenience.
6. **Compare the total weighted score (the weighted sum of the positives minus the weighted sum of the negatives) for each column to help you select the best concepts.**

   Tip Use the concept generation process and the Pugh Matrix in repeated rounds to help develop "super concepts." To develop these super concepts, after the first round of ranking, create new concepts by:

   - Synthesizing the best features of the different alternatives into new concepts.
   - Enhancing the strongest concepts by adding features from the unselected concepts to address weak areas.

   Follow this second round of concept generation with another round of ranking using the Pugh Matrix. Repeat this concept generation/concept selection process until you have one or two new super concepts that emerge during this process.

A Sample Pugh Matrix

CTQs from QFD 1	Baseline (Current process)	Telephone ordering	Internet ordering	Point-of-sale connection	Importance rating
Percentage of customer-desired technologies supported	S	S	S	-	68
Number of hours help facility is available	S	S	S	S	49
Number of process steps	S	S	S	+	57
Percentage of information directly accessible by customer	S	S	+	-	50
Percentage of historical information not requiring reentry	S	S	+	+	57
Number of hours access is available	S	S	S	S	51
Sum of positives	0	0	2	2	
Sum of negatives	0	0	0	2	
Sum of sames	6	6	4	2	
Weighted sum of positives	0	0	107	114	
Weighted sum of negatives	0	0	0	118	
Total weighted score	0	0	107	-4	

Concept Selection Legend: Better = + Same = S Worse = -

3.5 Review the Concepts

A design review objectively evaluates the quality of a design at various stages of the design process. It provides an opportunity for voices external to the design team (including those of the customers) to provide feedback on the design as you develop the process, product, or service.

A well-conducted design review ensures that the design will satisfy customers and the design process will function effectively to produce a high-quality process, product, or service.

Design reviews are quality control tools applied to the design process. They ensure the effectiveness of the design (i.e., the features provided by the design will meet customers' aesthetic and performance needs) and the efficiency of the design process (i.e., the teams responsible for the various elements of the design are working in a coordinated fashion that minimizes rework and duplicated efforts).

> ***Tip*** Design reviews are different from tollgate reviews. Design reviews focus on obtaining input on the design from outside of the design team at several key stages during the design process. Tollgate reviews focus on the design methodology and overall project issues and risks at the end of each step in the design process and whenever significant project problems or risks are identified.

When conducting a design review, remember to:

- Ensure that the design review gets both internal and external input.
- Focus on identifying and resolving problems during the reviews, and use the feedback you receive to make changes immediately to the design.

Tip Projects may have different places in the design process where a design review is needed. Organize a design review whenever external feedback appears appropriate or when there are coordination issues. Conduct multiple design reviews at any stage necessary to ensure the quality of the process, product, or service. It is especially important to conduct:

- A concept review after identifying one or two key concepts and determining their feasibility.
- A high-level design review after designing and testing a selected concept to some level of detail but before beginning the detailed design.
- A pre-pilot design review after completing the detailed design, but before the process, product, or service is ready to be piloted.

A concept review obtains feedback from customers and other interested parties (other organizational entities, suppliers, etc.) about the concepts that were selected. The feedback obtained during the concept review is a critical check on the design team's thinking. It can provide insights that lead to modifications of the selected concept(s) early in the design process when changes are easier to make and risks and costs can be minimized.

How do I do it?

1. **Determine the evaluation criteria and targets.**
    - Develop evaluation criteria for the concepts from the CTQs and any other constraints identified in the Pugh Matrix. Consider:
        - Completeness (i.e., which functions are included in the concept and which are excluded?).
        - Performance (i.e., how does the concept perform against the most important CTQs?).

    - Operating details (i.e., how will the customers/organization/suppliers interact with the product or service described in the concept?).
    - Aesthetics (i.e., how does the process, product, or service look and feel? How does the operating environment look and feel? How comfortable and safe do customers feel when using the process, product, or service?).
    - Cost (i.e., what is the approximate cost of delivering the process, product, or service?).

Tip Develop very specific criteria. The more specific the criteria, the more precise the feedback can be.

2. **Select the participants for the design review.**

- Be sure to select a small number of participants whose feedback is critical and who will provide honest and constructive feedback. Focus on participants who will help identify all of the factors that may affect the success of the design in the market. Include:
    - Key customers (about 10–15 customers).
    - Technology innovators: Those whose views may represent future trends in the industry.
    - High-volume users: Those who are likely to purchase a large amount of the product or service if the design meets their needs.
    - Pilot partners: Those who may be willing to try out the process, product, or service during the pilot.
    - Early adopters.
    - The general public.
    - Key suppliers (2–3 suppliers).
    - Key stakeholders and senior leadership.

Tip Not all customer groups may be relevant for all projects. Also, because the number of customers is small, be sure to carefully distinguish individual viewpoints from general themes. Different customer groups may have different preferred concepts; you may need to balance different viewpoints and preferences.

3. **Develop design review checklists and evaluation sheets.**
   - Proper documentation is critical for both describing the design and collecting feedback. Be sure to include the following types of documents in your concept review:
     - A review agenda and format that details how you will conduct the review and describes the important steps that you must cover
     - A concept depiction that may include descriptions on paper, drawings, photographs, prototypes, models, blueprints, data, calculations, and anything else that will help explain the concept to the participants
     - A data collection checklist that lists the data that you need to collect for all of the key aspects of the design and consists of sampling schemes, formats, surveys, questionnaires, guides, and other documents that support data collection
     - An improvement checklist that lists the findings in order of priority, lists the actions that you need to take to make corrections where needed, identifies the owners for these actions, and sets up times by which these actions need to be completed

4. **Collect and analyze the data.**
   - Because there are only a small number of participants in a design review, be sure to collect

data from multiple sources to provide a broad range of data and depth to the feedback, including:

    - Verbal descriptions of the participants' impression of the concepts.
    - Videotapes of participants interacting with the product or service.
    - A ranking or rating by the participants of the attributes of each concept.
    - A ranking of overall concepts.

- Several types of data analysis may be appropriate depending on the type of data you collected. You can conduct analysis of both qualitative responses to questionnaires/interviews and quantitative data from surveys. (In practice, most data analysis is qualitative.) Typical types of analyses include:
    - An in-depth video analysis to identify common difficulties that customers face in using the process, product, or service.
    - Qualitative data analysis of verbal data to identify common themes about customer likes and dislikes.
    - Statistical analysis (if possible) to quantify priorities and preferences.

5. **Identify and document actions based on data analysis.**

- Answer the following questions, based on the results of the data analysis:
    - Is there a clearly preferred concept?
    - If not, are there particular preferred attributes belonging to different concepts that we can combine to create a single preferred concept?
    - If there is a preferred concept, do we need additional analyses to resolve concerns and issues?

- Who is responsible for the resolution of key items and when?
- Is there a need for another concept review?

6. **Debrief the concept review session for future learnings.**
   - Note what worked and what didn't work in the design review session to improve future sessions.

   Caution: Of all of the design reviews, participants in concept reviews tend to be the most critical because much of the design is still in the idea stage. Do not get discouraged or annoyed with the criticism or ignore the feedback from a concept review. Ignoring feedback is the most common cause of a failed review session. Other causes of failed sessions include:

   - Poor or inadequate preparation.
   - Poor or inadequate documentation.
   - Discouraging open and frank communication.
   - Selecting only "friendly" participants.
   - Not having the right design team members.

   If, unfortunately, you experience a failed session, the debriefing will be a critical component for moving forward. After the debriefing, you may find that you need to adjust the concept(s) and perform an additional concept review before continuing the DMADV process.

3.6 Hold a Tollgate Review

Note: For general information on tollgate reviews, see section 1.5 in the Define step.

Before moving from the Analyze step on to high-level design, be sure to hold a tollgate review.

The tollgate review for the Analyze step focuses on:

- A list of key functions.
- A list of top concepts.
- The Pugh Matrix.
- The concept review outputs.
- A risk analysis update.

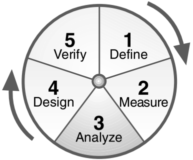
This tollgate review can lead you to:

- Proceed to the Design step.
- Redo your work on concepts, the concept review, and the tollgate review.
- Stop the project.

How do I do it?

1. **Update the Storyboard.**
2. **Present a progress report at the tollgate meeting using the Tollgate Review Form.**
   - Review and revise the Tollgate Review Form used at the end of the Measure step.
3. **Discuss the progress report and any issues that arise. Ask and answer questions about data and logic.**
4. **Identify the strengths and weaknesses of the project so far.**
   - Identify the strengths and weaknesses in using the DMADV methodology.
5. **Decide on the next steps for the project.**
6. **Identify the strengths and weaknesses of the concept review.**

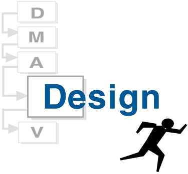
The Analyze Tollgate Review Form



Analyze:
Select the concept that
best meets the CTQs

Deliverables:
- ❑ List of key functions
- ❑ List of top concepts
- ❑ Selected concept
- ❑ Updated risk plan
- ❑ Updated Storyboard presentation
- ❑ Updated project plan

- What are the most important functions that must be designed to meet the CTQs?
- Which parts of the process, product, or service require innovative new designs to maintain a competitive advantage?
- What are the top concepts developed (for each function)?
- What criteria did you use to evaluate and select the best concept?
- What are the risks associated with each concept?
- Does the project charter require any revisions?
- What limitations or barriers have you encountered?
- Review your project plan; are you on track?
- What are your key learnings from the Analyze step?
- What are your next steps?



Why do it?

To develop high-level and detailed designs, test the design components, and prepare for the pilot and full-scale deployment.

Tools used in this step:

- The QFD Matrix
- Simulation
- Prototyping
- The Design Scorecard
- Failure Mode and Effects Analysis (FMEA)/Error Mode and Effects Analysis (EMEA)
- Planning tools
- The Process Management Chart
- Tollgate Review Forms

Note: Additional resources for these tools can be found in the Appendix.

Outputs of this step:

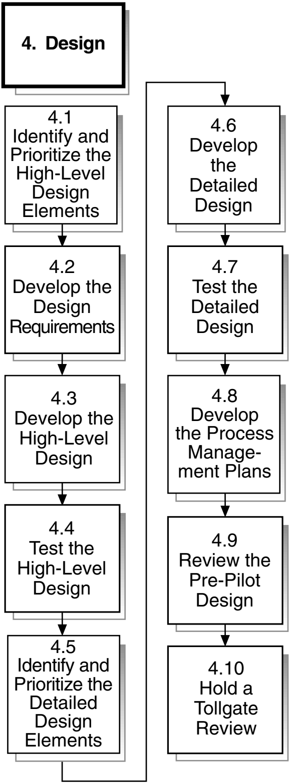
- A tested and approved high-level design
- A tested and approved detailed design
- A detailed, updated risk assessment

- A plan for conducting the pilot
- Completed design reviews and approvals
- A tollgate review and updated Storyboard

Key questions answered in this step:

- What are the key design elements that the final design must include?
- How do we prioritize these design elements?
- How can we distribute the design work among sub-teams?
- How do we ensure that these sub-teams communicate effectively with each other during the design process?
- At what point will we "freeze" the design?
- How do we test the design to ensure that it will work before implementation?
- How do we identify weak points in the design that may be susceptible to failure?
- How do we plan the pilot to ensure that it is realistic and produces meaningful results?

How do I do it?


4. Design
4.1 Identify and Prioritize the High-Level Design Elements
4.2 Develop the Design Requirements
4.3 Develop the High-Level Design
4.4 Test the High-Level Design
4.5 Identify and Prioritize the Detailed Design Elements
4.6 Develop the Detailed Design
4.7 Test the Detailed Design
4.8 Develop the Process Manage-ment Plans
4.9 Review the Pre-Pilot Design
4.10 Hold a Tollgate Review

The Design step encompasses both *high-level design* and *detailed design*. This two-phased high-level/detailed design approach allows you to:

- Make decisions about the major design *components* and how they fit together before expending effort and money on detailed decisions, resulting in a more-stable and robust design.
- Evaluate the *performance and feasibility* of the high-level design before spending more resources on the detailed design (to make the design process more cost-effective and efficient).
- Better understand the *risks* associated with the design.

Tip The overall approach to developing both high-level and detailed design is the same; only the level of specificity differs. The high-level design includes enough detail to allow you to evaluate the design's performance and feasibility. (You may need to test several high-level design alternatives before selecting a suitable design.) The detailed design further develops the selected high-level design to enable you to test and implement the design.

This process is truly repetitive in nature; after selecting a high-level design, you repeat the design steps until you reach a level of detail sufficient to pilot a solution.

The challenge of the design process is to make choices that simultaneously balance the benefit, cost, and risk elements and that are compatible with previous strategic decisions.

4.1 Identify and Prioritize the High-Level Design Elements

How do I do it?

1. **Identify the high-level design elements.**

   The design elements are the basic descriptions of the components needed to make the process, product, or service work. They answer "what is needed."

   It may help to think of and describe the design elements in categories. Common categories to consider include:

   - Product/service elements.
   - Process elements.
   - Information systems elements.
   - Human systems elements.
   - Equipment.
   - Materials/supplies.
   - Facilities.

   Tip You may not need to include all of the elements listed above in your design; use this list of elements simply to ensure that your design is complete and includes everything you need to be successful.

   Using the list of design elements to ensure completeness in the design will also remind you to integrate the design of products with related processes, in a process called *product and process planning*. In addition to meeting customer requirements, the product must interface well with relevant processes such as manufacturing, packaging, distribution, and technical support, and it must fit well with suppliers' processes.

Designing the products and processes together allows:

- Process capabilities to be addressed or taken into account by the overall design.
- Inspection, wait, transport, and rework steps to be minimized by the design.
- Data collection for ongoing monitoring to be designed into the process.

To identify all of the necessary process elements for the design, follow the product or service as it would actually flow through the organization. Once you have mapped the path through the organization, identify value-added and non-value-added areas in the process to show where you will need to redesign current processes, and analyze gaps in the design to identify where you will need to create interfaces with existing processes.

Tip When redesigning a process, product, or service, you may be able to reuse some parts of an existing design; in such cases, you may only need to design the new elements and interfaces. Even with new designs, you may be able to use "off-the-shelf" or existing designs for the least important elements; you may need to create innovative or breakthrough designs only for the most important elements.

The design elements for our multichannel order placement process could include:

- The order processing equipment.
- The order process itself.
- Order processing agents.
- An order processing facility.

Design Elements for the Order Placement Process

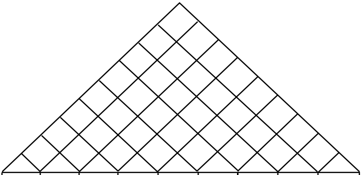
Element category	Element description
Product	• Order entry form
Process	• Order placement process
Information systems	• Interactive Voice Response (IVR) scripts • Order processing system/ database
Human systems	• Order processing agents
Equipment	• Fax • Phone network • IVR hardware
Materials/supplies	• A list of materials and supplies
Facilities	• Order processing center

2. **Prioritize the design elements to determine which are the most important ones to focus on.**
   - Use a QFD Matrix (QFD 3) to help you focus on the design elements that will have the greatest impact. (The most important design elements will impact the most important functions, and understanding the relationship between CTQs, functions, and design elements will help establish clear requirements for the critical design elements.)
     - Create the QFD 3 Matrix with the functions in the rows and the design elements in the columns. (When designing products, you may need a separate QFD Matrix for each design element category.) For each element/function relationship, ask, "To what extent does this

element impact the design's ability to perform this function?" Use the 9, 3, 1 scale you used previously to record the strength of the relationship and use matrix multiplication to help summarize your answers.

Tip In product applications, the objective of the linked QFD Matrices is to formally deploy requirements (quantitative specifications) from the CTQs to the functions to the design elements. For service or process applications, the QFD Matrices follow a more informal approach to primarily help you to determine where to focus your design efforts. Service and process applications will often use a total of only two or three QFD Matrices to establish the CTQ linkage down to the functional level. Manufacturing and engineering design applications may require more QFD Matrices to establish the CTQ linkages from the high-level customer needs to the component level of the design.

QFD 3 Matrix
for the Order Placement Process



	High-Level Design Elements								
Functions	Order entry form	Order placement process	Business rules applications	Order processing agents	Order processing system/database	Order processing center	Multichannel switch	Application servers	Importance of functions
Enter order	9	9	9	3	9		9	9	4.2
Check for errors	3	9		9		1			2.5
Confirm order receipt		9	9	9			3	9	1.6
Transmit order		9			9	1	9		1.6
How important	45	89	52	50	52	10	57	52	

This example matrix shows that the order placement process itself is the most important high-level design element (which is typical for service applications because the process drives the design). Because this is an application involving the internet, the switch and the internet application hardware and software are also important, followed by the order processing agents (who are primarily available for backup support), the supplies, and, lastly, the facilities.

The information in this matrix is particularly valuable. Typically, teams place a lot of emphasis on the technology in the design and do not spend much time designing the process itself. But without a good process, the technology cannot function adequately. By using a QFD Matrix such as the one on the previous page, the importance of the "work" process (the order placement process) becomes evident and the need to focus on it, as well as the technology, is clear.

4.2 Develop the Design Requirements

The design requirements are the quantitative performance specifications for each element of the design. They describe how the design elements must perform to allow the designed process, product, or service to meet the CTQs. They answer "how much of each element is needed" and "how each design element should perform," to help you select the most appropriate design alternatives for implementation.

Note: The performance requirements for functions and elements resemble CTQs in that there is a measure with a target and specifications for the measure, but these requirements are more specific than the CTQs.

How do I do it?

1. **Develop the design requirements by quantitatively modeling the relationship between the output performance requirements of the design (the CTQs that the design team developed in the Measure step) and the process or input variables that impact the output performance.**

   Tip When designing a new product, include designs-for-manufacturability, designs-for-reliability, designs-for-maintainability, and designs-for-life-cycle cost. These will add requirements that flow through the entire design process and should be considered when developing design requirements.

- Use the $y = f(x)$ formula to describe the relationships between the CTQs and the process variables that impact the CTQs.

  The $y = f(x)$ formula states that an output (y) is a function (*f*) of the variables (x) that directly affect the output. Here, the output performance requirements of the design (the CTQs) constitute the y and the design element requirements that impact the CTQs comprise the x. The $y = f(x)$ formula is a simple way to illustrate the causal relationship between the CTQs and the design elements, and to show which variables or inputs you will need to control to ensure that the design will meet the performance requirements.

Tip The output performance (y) can be a function of many variables (x_1, x_2, x_3, etc.) that will impact performance.

$$y = f(x_1, x_2, x_3, \ldots x_n)$$

- There are three levels of $y = f(x)$ relationships:
  - The strategic level (i.e., how the performance of each major service attribute [x] affects the performance of the business [y])
  - The service level (i.e., how the performance of each process [x] affects the performance of the service attribute [y])
  - The process level (i.e., how the performance of the process steps/functions [x] affects the performance of each process [y])

Note that the measures and requirements at different levels are linked. The y's of the lower levels become the x's of each successively higher level as you proceed from the process level to the strategic level.

Order Placement Process Example

Level	y = *f* (x) relationship
Strategic level	Market share = *f* (satisfaction with order processing, satisfaction with service delivery, satisfaction with customer service, satisfaction with billing)
Service level	Satisfaction with order processing = *f* (percentage of customer technologies supported, number of process steps, percentage of historical information not requiring reentry)
Process level	Percentage of historical information not requiring reentry = *f* (percentage of database capacity used for historical information)

The example shows that, at the strategic level, market share is influenced by customers' satisfaction with various aspects of the service. Satisfaction with each aspect of the service (the service level) depends upon the performance of each aspect relative to key CTQs (e.g., the satisfaction with order processing depends on the performance of the order processing process relative to the CTQs identified by the design team in the Measure step). Finally, the performance of each process (the process level) depends upon the design elements that make up the process and the performance specifications of the design elements.

Tip For high-level and detailed design, *focus on the process level relationships* (because they deal with design elements and performance specifications). Develop these process level relationships using:

- Business knowledge.
- Benchmarks and analogies.
- Trials and prototypes.
- Experiments.
- Simulations.
- Data analysis.

- Use $y = f(x)$ relationships to develop the design requirements for all of the important design elements identified in the QFD 3 Matrix. The design requirements could specify a particular design alternative, a performance requirement for the element, or the number of units of a particular element needed for the design.

Tip There is no magic to developing the $y = f(x)$ relationships. To develop these relationships, you simply need data on the input variables and the output.

When redesigning a process, product, or service, you can develop design requirements using data from existing processes. However, with new designs, input and output data is often not easily available, so you must use a combination of methods to compile this data. Business knowledge, coupled with benchmarks from comparable processes, can serve as initial guides for defining these relationships. If you require more-precise definitions (such as in high-risk designs), you may need to collect data using demonstrations, testing, or limited trials to estimate these design requirements. Simulations (explained in greater detail later in this chapter) can also help in identifying y = *f* (x) relationships in situations where precise data does not exist.

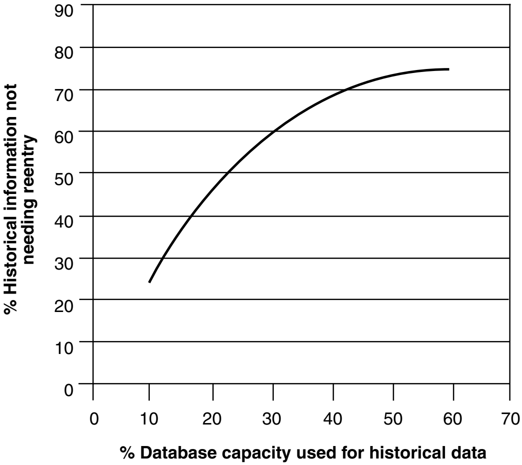
When developing y = *f* (x) relationships:

- Select only key CTQs.
- Select only unusual/complex relationships to model.
- Simplify the y = *f* (x) relationships to include only the most important input factors.
- Use benchmarks, analogies, and existing data where possible.

A Graphical Representation of a y = *f* (x) Relationship with Diminishing Returns

CTQ = Percentage of historical data not needing reentry

Design requirement = Percentage of database capacity used for historical data



In this example, the capacity of the database needed to store historical information (the design requirement, x) increases nonlinearly with the amount of data not needing reentry (the CTQ, y), possibly because the complexity of the historical data increases after a few basic pieces of historical information have been stored. Recall from the work in the Measure step (summarized in the QFD 1 Matrix) that the target for the percentage of historical information not requiring reentry is 90%; clearly this present database is incapable of meeting this requirement. A larger database or one with a different storage algorithm must be found.

Tip In some cases, it may help to develop an intermediate level of requirements (between the concept level requirements and the design element requirements) before you determine the requirements for the high-level design, especially if the relationships are complex or if only some of the elements are being designed. This "design decomposition" is also useful if different teams are responsible for different aspects of the design. (This approach is more common for the design of products and is less critical for the design of services or processes.)

Caution: Developing the performance requirements for elements is often difficult and time-consuming. Enlist the help of experts knowledgeable about the process, product, or service, and experts in statistics, if necessary.

Tip You can also use Design of Experiments (DOE) to explore the relationships between multiple process variables and the output performance requirements. DOE is a systematic method to aggressively learn about a process, product, or service by manipulating multiple settings in the design. DOE can help you:

- Identify the factors that affect the performance measures.
- Test cause-and-effect theories.

- Understand the relationships among design factors.
- Optimize process, product, and service designs.
- Design robust processes, products, and services.
- Improve your ability to manufacture the design.
- Improve the reliability of the design.

Note: An in-depth explanation of DOE is beyond the scope of this book. For more information, consult *The Six Sigma Memory Jogger™ II* or *The Black Belt Memory Jogger™*.

Design Element Performance Requirements for the Order Placement Process

Element description	Requirements
Order placement process	• Not more than four process steps • Average order placement cycle time of 120 seconds with an upper specification limit of 180 seconds
Order processing system/ database	• Not more than 30% capacity used for historical data • Transaction rate > 5 transactions/second • Response time < 5 seconds • Network throughput > 500 Kbps
Fax, phone network, and IVR hardware	• Ability to handle up to 100 agents • Skill-based routing with up to twenty skill codes • Automatic call distributor (ACD) handling up to ten voice/fax calls in queue • Router speed of 0.36 seconds/ package
Application server capacity	• One server • Maximum bandwidth of 2 x 10^{12} bytes/hour • Capacity of 12,000 requests/ hour • Three transactions per minute

4.3 Develop the High-Level Design

The high-level design is a combination of prototypes and designs on paper that are developed to a level of detail where it is possible to predict and test the performance and feasibility of the design.

To develop the high-level design:

1. **Reconfigure the design team.**
2. **Develop the design.**

4.3.1 Reconfigure the design team

1. **Divide or partition the design.**
    - Common methods to divide or partition the design include *intrinsic partitioning* and *extrinsic partitioning*. Intrinsic partitioning (i.e., internal to the design) divides the design tasks so that similar parts of the design are designed together. It is more efficient than extrinsic partitioning, but is more difficult to do. Extrinsic partitioning (i.e., external to the design) separates the design tasks by convenience (e.g., partitioning by customer segment, technology, or geography). It is easier than intrinsic partitioning but can result in overlap and duplicated work if you do not adequately coordinate the activities of any necessary sub-teams.
2. **Determine if sub-teams are appropriate.**
    - As you develop the design, you may be able to split the design tasks among several sub-teams, particularly if the project is large and complex. (For example, a new aircraft design might have sub-teams for the major components [wings, tail, cockpit, etc.] and "sub-sub-teams" within, focusing on designing the electrical, mechanical, ergonomic, and process elements of each component.)

    Choose someone from the "core" design team to lead each sub-team, but staff the teams themselves with subject matter experts. Divide the teams by design element category and give the core design team the coordination responsibilities for the entire project.

For each sub-team, decide:

- How to manage the sub-teams.
- What people resources are needed.
- Where the resources will come from.
- Whether the resources should be full time or part time.
- Which sub-teams will be responsible for which design tasks.

3. **Include all affected managers and project team leaders in staffing discussions.**

   - Staffing the sub-teams will require discussion and negotiation among all affected functional managers and project team leaders because:
     - The organization will need to meet both functional and project objectives simultaneously, which may require the same resources. Managers and team leaders may need to negotiate the allocation of these resources.
     - Implementation of the new design will require support from the functional managers. Involving these managers as early as possible in the activities that affect them will help them develop a positive attitude toward the project.

4. **Create charters for the sub-teams.**

   - Create charters similar to the overall project charter to allow the sub-teams to work efficiently and effectively. Include:
     - A purpose.
     - A schedule and deadlines.
     - The scope or boundaries for each sub-team's part of the design.

- A description of each team member's responsibilities and functions.
- A clear relationship with the core design team.
- Communication and coordination mechanisms.

5. **Decide if you will use vertical management or horizontal management to coordinate the work of the sub-teams.**

   - Use vertical management to create a hierarchy of sub-teams from higher to lower level. Vertical management ensures that the design tasks at the lower levels are well-integrated and support the common direction set by the higher level tasks. The lower level teams will work on the same design tasks as higher level teams, but at different levels of detail. The higher level sub-teams will meet once or twice a month to set the direction for the project work and then pass this direction on to the lower level sub-teams to complete the design. The lower level sub-teams will meet often (once or twice a week) to communicate and compare notes. They will pass a single, integrated solution on to the higher level teams, who will then determine the next set of design tasks for the lower level teams.

   - Use horizontal management to ensure that diverse parts of the design are integrated, and that the overall design is proceeding according to plan. Sharing best practices across complementary parts of the design ensures that rework and errors are minimized and that the best efforts of every sub-team are freely available to all other sub-team members.

     One or more high-level sub-teams will coordinate horizontal management in meetings once or twice a month. One person (usually the team leader) from each lower level team or set of teams will attend these meetings to synchronize the timelines and share best practices among the teams involved in complementary but non-overlapping parts of the design.

4.3.2 Develop the design

1. **Complete the design of all of the supporting elements defined earlier.**

   - Develop a description of each design element to meet the design requirements. Your final high-level design should include the following elements and deliverables:

Element	Deliverables
Product	• Descriptions and drawings • Legal and regulatory impacts • Models and prototypes • Specifications
Process	• Process flowcharts • Process deployment maps
Information systems	• A logic design • A physical design • A hardware design • Test plan/software scripts • A data migration plan • Test and production equipment • A description of the facilities needed
Human systems	• Job/task analysis • Ergonomic analysis • A training design • Reward and recognition plans • An organizational design • Employee development plans
Equipment	• Descriptions and drawings • Specifications
Materials/ supplies	• A bill of materials • Forms designs • Purchasing and inventory impacts
Facilities	• Architectural drawings • Scale models • Computer models • Layout diagrams

Tip You can develop designs bottom-up, top-down, or in combination. In practice, it is generally preferable to determine the requirements top-down but develop the design bottom-up to ensure that you have included all of the critical elements in your design.

Tip Use common design principles as guidelines to help you produce a higher quality, simpler design. Some common design principles to consider include:

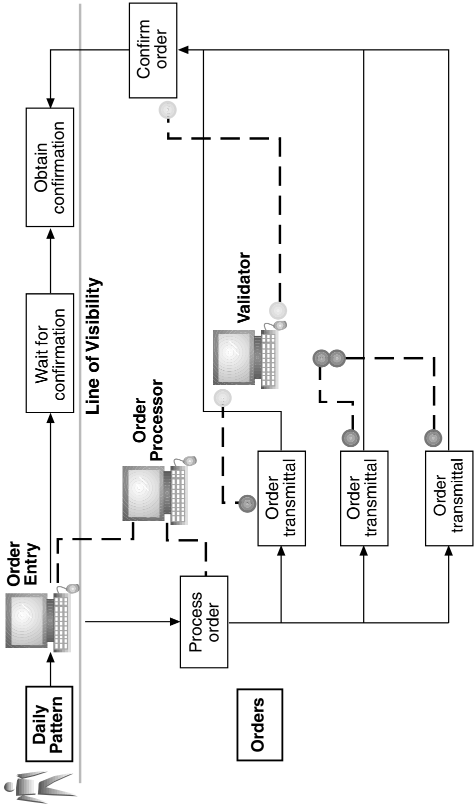
- Never carry out a design without reference to the selected concept.
- Consider the interactions between the various areas of your design.
- Ask if there is a simpler way to accomplish a function.
- Determine if you can eliminate an element altogether.
- Ask if any parts of the design can cover multiple functions.
- Determine if you can combine sections of the design.
- Ask if you can assemble the design from standard parts.
- Outsource tasks or processes that are not core competencies.
- Minimize the number of different people that interact with the customer.
- Consider relocating work to/from the customer.
- Make decisions early in the process to improve efficiency.
- Make decisions late in the process to improve flexibility.

  - Minimize handoffs and non-value-added activities.
  - Maximize the percentage of value-added time per elapsed time.
- When making design decisions, consider:
  - The required performance range.
  - Environmental conditions.
  - The shelf-life of the process, product, or service.
  - Its reliability under stress.
  - The ease of maintenance.
  - Cost.
  - Safety.
  - Aesthetics.
  - Ergonomics.
  - The ease of standardization or conformance to published standards.

Consideration of these factors will help you as you select design alternatives. Gather information about these factors from subject matter experts, benchmarking data, market research, product knowledge, and business requirements.

The high-level design for the process, human systems, and information systems elements for our order placement process design could include the following four graphics:

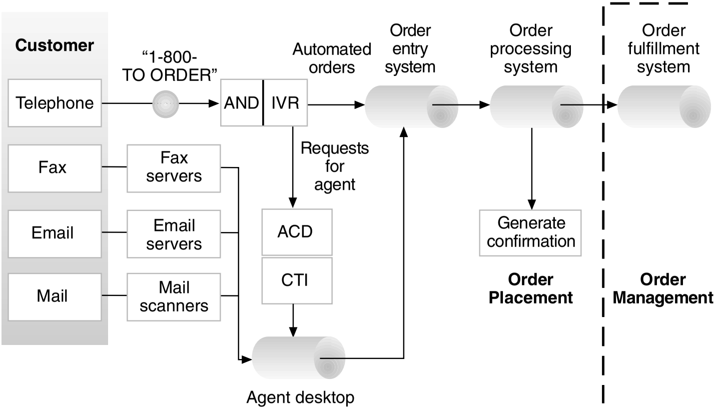
A Process Map
(the Process Element)



Agent Job Requirements (the Human Systems Element)

Requirements	Descriptions
Leadership	• Takes initiative and positively influences others to get things done • Willingly embraces and promotes change
Teamwork	• Collaborates and/or coordinates with others to ensure the job gets done • Actively participates on assigned teams • Balances team and individual goal accomplishment and recognition
Customer focus (internal and external)	• Actively listens to the customer, seeks input from customers, and maintains professional demeanor at all times • Identifies the appropriate customer with whom to work • Proactively meets customer needs and follows through on customer/consumer commitments in a timely manner
Decision making	• Makes fact-based decisions in a timely manner
Interpersonal and communication skills	• Actively listens and checks to ensure intended meaning is understood • Communicates clearly, directly, and honestly, both verbally and in writing
Job knowledge	• Thoroughly knows all menus and screens of the desktop and is able to use them effectively • Knows the screens of the order entry system and is able to guide customers through the system • Is able to access status screens of the order processing system and provide confirmation • Has excellent telephone skills

An Architecture Map
(an Information Systems Element)



AND = Automatic Number Directory
IVR = Interactive Voice Response
ACD = Automatic Call Distributor
CTI = Computer Telephone Interface

An Application Server Hardware Design (an Information Systems Element)

Purchase IVR hardware with the following requirements:

- An open, scalable, standards-based framework that forms a unified foundation for customer interaction and enables the real-time integration of diverse media types (including phone, fax, email, and the web) with the ability to accommodate emerging interaction mediums in the future
- A broad suite of call center applications, including inbound and outbound communications routing and reporting, that sit on top of the framework

4.4 Test the High-Level Design

Typically, a high-level design is tested as an integration of all of the elements to ensure that it meets the CTQs. Testing at this stage will also help to identify where pieces of the design do not align and will allow you to correct any problems before attempting a detailed design.

As you test the high-level design, you will determine how the performance of the overall design is affected by the performance of the parts, and how the performance of the output is affected by variability in the inputs.

How do I do it?

1. **Predict the performance of the design.**
2. **Review the high-level design.**

4.4.1 Predict the performance of the design

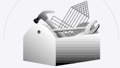
Because you do not have an operational process, product, or service yet, you cannot test the actual design. Rather, you must make assumptions about the expected performance of the combined design elements that you have developed and check to see if the overall predicted design performance will meet the CTQs, based on these assumptions.

Clearly, a decision to move forward carries a risk; however, if the assumptions are carefully thought out, the risks associated with this approach are less than the risks associated with building the product or service with no tests at all.

To predict the high-level design performance:

1. **Estimate the performance (mean and variability) of each part of the design.**
2. **Use Simulation to aggregate the performance of the parts and/or Prototyping to test a smaller working verision of the design, to predict the mean and variability of the overall performance. You can also use a Design Scorecard to aggregate sigma scores and predict design performance, especially for product designs.**

Simulation



What is it?

Simulation allows you to draw conclusions about the behavior of a real or proposed process, product, or service by studying the characteristics of a model. Simulation models help you evaluate the trade-offs between performance and resource requirements to determine an "optimal" design.

Why use it?

- To predict performance when the design is complex or when the risk of failure is high
- To easily change the design or perform "what-if" analysis
- To provide instant feedback of results

- To eliminate the risk of injury or environmental damage
- To reduce raw material or production labor waste

How do I do it?

1. **Specify the problem or questions you wish to test.**
    - Ask:
        - What am I trying to do or predict?
        - What output variable am I trying to measure?
2. **Build a model.**
    - Define the model inputs:
        - Use process flowcharts.
        - Describe the performance in terms of average and variability.
        - Describe the capacity (i.e., the number of resources for each step, volume descriptions, or schedules and shift information).
    - Define the model outputs, including the mean and standard deviation of the overall performance and any other performance metrics specified by the CTQs.
3. **Quantify the model.**
    - Use data from historical records and interviews with subject matter experts.
    - Observe a similar process, product, or service.
    - Use known physical relationships or engineering calculations.
    - Consider using DOE.
4. **Verify and validate the model.**

5. Plan and run model scenarios.

- Use the model scenarios to aggregate the performance of the parts to predict the mean and variability of the overall performance.

6. Analyze the results and draw conclusions.

- Compare the average predicted performance with the CTQ performance targets and compare the variability in performance with the CTQ specifications.

7. Make recommendations for adjusting the design.

- Redesign the product or service as necessary and test again.

A Simulation for our multichannel order placement process example could show:

Input: A change in the order arrival rate from 20/hour to 60/hour

Output: The mean and standard deviation of the order placement cycle time

Arrival rate (orders/ hour)	Average order placement time (minutes)	Standard deviation of order placement time	Process performance
20	12.28	0.11	Greater than 6 sigma
24	12.70	0.11	Greater than 6 sigma
30	14.39	0.11	Between 5 and 6 sigma
60	105.21	26.75	Failure

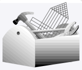
In this example, the relationship between performance and volume for a fixed capacity is steeply nonlinear after a certain volume level. As a result, while the process performance drops slowly between an arrival rate of twenty orders per hour and thirty orders per hour, the process fails by the time arrival rates of sixty orders per hour are reached. Therefore, the order placement time is very sensitive to an arrival rate above thirty orders per hour.

Recommendations for adjusting the design could include:

- Identifying the days in the year when the order volume is high.
- Ensuring that extra capacity is available on these days.
- Having a contingency plan for adding capacity quickly if needed.

If it is highly probable that the order volume will exceed sixty orders per hour once or twice a day, then the design is inadequate and redesign and retesting is necessary. But if order volume rarely goes above thirty orders per hour, a contingency plan for adding extra capacity might be sufficient.

Prototyping



What is it?

Prototyping creates a smaller working version of the process, product, or service to allow you to test the design.

Why use it?

- To test one or more elements of the design in greater detail
- To manage risk and uncertainty (particularly for high-risk components or subsystems of the design)

How do I do it?

1. **Identify the highly focused specific questions or limited number of technical issues you want to investigate.**
2. **Determine the key interfaces (e.g., customer to component, critical component to critical component, etc.) that you want to focus on.**
3. **Select a prototype.**
   - Use something that already exists to test the concept (i.e., modify an existing product or repackage a competitor's product) or simulate the end product without providing the actual product itself (i.e., create components that look and feel like the end product or put components together to simulate the product's end function).
4. **Test the prototype.**

Design Scorecard

What is it?

The Design Scorecard allows you to collect, display, and analyze the facts of a product design to predict future performance and improve upon the initial design. The scorecard compares the customer CTQs to the predicted performance of the design elements to see how the design is progressing.

A typical Design Scorecard includes five component scorecards: the performance sigma scorecard, the parts sigma scorecard, the process sigma scorecard, the software sigma scorecard, and the top-level scorecard (which is a summary of the other four scorecards). (Note: The specific component scorecards you use may vary with the product you are designing [e.g., you might not need a software sigma scorecard if no software is involved in the design], but the scorecard generation would be similar.) You can categorize the data entered into each of the component scorecards under four main headings: CTQ/parameter details, the Voice of the Customer, the Voice of the Product, and performance metrics.

Why use it?

- To predict performance, using a statistical model
- To optimize a design
- To recognize missing key elements or issues in a design
- To locate areas in the design that need improvement
- To communicate with all stakeholders
- To record design progress and store lessons learned

Note: The primary purpose of the Design Scorecard is to encourage and support a dialogue within the design team. The questions the team asks when using the scorecard are more powerful than using the scorecard to drive toward a set answer or sigma score. (Ultimately, it will be the customer or end user who will determine whether the design is satisfactory, not the scores on a scorecard.)

As you discuss the Design Scorecards, ask the following questions to initiate a dialogue about your design:

- What are the customer expectations?
- What are the capabilities of the parts, process, and product?
- What is the current Voice of the Process (i.e., the information about how all of the process variables within a process and the process itself are performing)?
- How can we create a robust design?
- Have we included all parties and processes?
- Are there any gaps between reality and prediction?
- What are the intended consequences? Unintended consequences?
- Can this success be replicated?

Note: An in-depth discussion of the Design Scorecard is beyond the scope of this book. For additional information, see *Design for Six Sigma: A Roadmap for Product Development* by Kai Yang and Basem S. El-Haik, McGraw-Hill, 2003.

How do I do it?

1. Create a performance sigma scorecard.

- Include all of the important product performance parameters. Use statistical estimates to measure the effect that component variation will have on product performance and to measure product behavior against customer specifications.

Tip Use either attribute defects per unit (DPU) or variable data in the calculations for the performance sigma scorecard. The data you use in this scorecard can come from FMEA analysis, benchmarking, QFD Matrices, test designs, Simulations and analysis, product test data and results, customer complaints and audit results, and contracts and warranty issues.

a) Determine the performance parameter details.

- List all critical performance parameters (or CTQs) associated with the product.
- Assign metrics and units to each of the critical performance parameters.

b) Record the Voice of the Customer data.

- For parameters measured using variable data, obtain a target and specification limits. (Note: The specification limits might be one-sided.)
- For parameters measured using attribute data, obtain the target defect level (usually 0).

c) Record the Voice of the Product data.

- Denote the data collected as either long-term (LT) data or short-term (ST) data.
- Enter the observed mean and standard deviation or parts per million (PPM) defects for the measured performance parameters.

d) Record the performance metrics.

- Calculate the sigma value for the upper specification limit (Z USL), the sigma value for the lower specification limit (Z LSL), and the defects per unit (DPU) for each performance parameter.
- Calculate the rolled throughput yield (RTY) for each performance parameter, using the equation:

$$\text{RTY} = e^{-\text{DPU}}$$

(**Note**: An in-depth discussion of sigma values and rolled throughput yield is beyond the scope of this book. For more information, see *The Black Belt Memory Jogger™.)*

Tip All DPU and RTY calculations should be based on long-term data. If you are using short-term data, you will need to approximate long-term DPU by assuming the relationship:

$$Z_{ST} = Z_{LT} + 1.5$$

(Note: This relationship is true for both Z USL and Z LSL [i.e., $Z\ USL_{ST} = Z\ USL_{LT} + 1.5$, and $Z\ LSL_{ST} = Z\ LSL_{LT} + 1.5$].)

- Calculate the total DPU for performance as the sum of the individual performance parameter DPUs. Then calculate the overall performance using the equation:

$$RTY = e^{-\text{total DPU}}$$

e) Interpret the information compiled in the performance sigma scorecard by asking:

- Is our yield or sigma value competitive?
- What are the drivers for this performance?
- Which parameters perform best? Which parameters perform worst?
- How critical are these parameters for our customers?
- Are any design trade-offs possible to improve performance?
- Are our measurement systems adequate?
- What are our model assumptions? Are they valid?
- How can I make a cost-based analysis?

Note: This discussion of the scorecard results will often lead to an improved version of the design and more-robust product performance.

The Performance Sigma Scorecard for a Treadmill

Parameter	Metric unit	Data type	Target	USL	LSL	LT/ ST	Mean	Std. dev.	Z USL	Z LSL	DPU	RTY
Quietness	sone	Variable	0	1.2		ST	0.8	0.15	1.17	N/A	1.21E-01	0.88603
Speed change	mi.	Variable	0.1	0.2	0.05	LT	0.1	0.06	1.67	0.83	2.50E-01	0.77871
Reliability	mi.	Variable	500		300	LT	350	30	N/A	1.67	4.78E-02	0.95333
Safety	no. of problems	Attribute	0			LT					1.00E-02	0.99005
										Total	**4.29E-01**	**0.65122**

Total number of parameters	4
Avg. defect per parameter	0.1072
Avg. yield per parameter	0.8983
Avg. parameter LT sigma	1.2720
Avg. parameter ST sigma	2.7720

Tip Use the information within the performance sigma scorecard to:

- Determine how robust the design is, subject to normal variation.
- Estimate the defects that the customer will experience.
- Determine if the defects are mainly due to design, reliability, or performance issues.
- Combine various CTQ levels into a single score for comparison.

When creating and using this scorecard:

- Start from the customer perspective.
- Identify and prioritize all of the customer CTQs.
  - Do not omit critical customer requirements.
- Translate the requirements into technical data.
  - Remember that variable data requires fewer samples than attribute data.
  - Make sure you have the most appropriate measure for the requirements.
- Perform measurement system analysis on the key metrics (i.e., make sure that the measurement system you are using to measure key metrics is reliable and accurate).
- Be aware of unexpressed assumptions (e.g., normality, units, etc.).
- Verify that the data represents long-term variation, and if the data is not normally distributed, transform it.
- Do not get caught up in unwarranted minutiae.

2. Create a parts sigma scorecard.

- Calculate the sigma scores (capability metrics) for the parts, sub-assemblies, and final assemblies used in the product. Use statistical estimates to determine the defect levels of incoming parts in terms of DPMO and PPM. (Include a parts list with defect-data-by-part to help you evaluate and choose high-quality suppliers.)
  - Combine the defect levels from all critical parts for a total score.

  Note: Use incoming inspection data, past experiences, similar parts, purchasing department data, supplier data, and external agencies' data as your sources of information for this scorecard.

a) Record the part CTQ details.

  - List the relevant part descriptors (e.g., supplier, part number, part name, etc.) for each part being measured.
  - List the quantity of parts per assembly or sub-assembly and sum to find the total number of parts used.
  - Assign metrics and units to each of the parts being measured.

b) Record the Voice of the Customer data.

  - For each part measured using variable data, obtain a target and specification limits. (Note: The specification limits might be one-sided.)
  - For parts measured using attribute data, obtain the target defect level (usually 0).

c) Record the Voice of the Product data.

- Denote the data collected as either LT or ST data.
- Enter the observed mean and standard deviation or PPM defects for the measured parts.

d) Record the performance metrics.

- Calculate ZUSL, ZLSL, and DPU for each part.
- Calculate the RTY for each part, using the equation:

$$RTY = e^{-DPU}$$

- Calculate the total DPU for parts as the sum of the individual part DPUs. Then calculate the overall part RTY using the equation:

$$RTY = e^{-\text{total DPU}}$$

e) Interpret the information compiled in the parts sigma scorecard by asking:

- What are the drivers for the current level of parts scores?
- Which parts are of the best quality? Worst quality?
- Would an alternate supplier improve the scores?
- What are the cost considerations?
- Is there a way to reduce the number of parts (e.g., adjusting the design so that some parts are not needed)?
- What are the possible trade-offs to improve?
- Are our measurement systems adequate?
- What are our model assumptions? Are they valid?

The Parts Sigma Scorecard for a Treadmill

Major part assembly	Major part no.	Minor part assembly	Supplier	Parameter	Metric unit	Data type	Target	USL	LSL	LT/ ST	Mean	Std. dev.	Z USL	Z LSL	DPU	RTY
Base assembly	CL006	Hframe	Gfab	Length	in.	Variable	43	43.2	42.8	LT	42.95	0.05	5.00	3.00	1.35E-03	0.998651
				Breadth	in.	Variable	13	13.2	12.8	LT	13.02	0.05	3.60	4.40	1.65E-04	0.999835
				Thickness	in.	Variable	0.27	0.3	0.24	LT	0.27	0.0102	2.90	2.98	3.29E-03	0.996712
		Pulleys	Gfab	Tension	lbs.	Variable	8	14	2	LT	8	1.81	3.314917	3.314917	9.17E-04	0.999084
				Width	in.	Variable	0.25	0.3	0.2	LT	0.255	0.0152	2.960526	3.618421	1.68E-03	0.998318
Base stabilizer	MA003	Adjustment Bracket	FlyByCo	Adjustment level	pass/ fail	Attribute	pass			LT					2.43E-04	0.999757
		Wheel Stop	FlyByCo	In position	in/ out	Attribute	in			LT					1.56E-04	0.999844
														Total	7.81E-03	0.992222

Note: This is a truncated version of a parts scorecard, which would include all of the parts and be more extensive.

Tip Use the information within the parts sigma scorecard to:

- Determine the quality level of key parts used in the design.
- Track the incoming defect levels of critical supplier parts.
- Improve communication among stakeholders.

When creating and using this scorecard:

- Include only the parts and assemblies that impact the CTQs.
- Use a good classification system for assemblies and sub-assemblies.
- Remember that variable data requires fewer samples than attribute data.
- Perform measurement system analysis on the key metrics.
- Do not omit CTQ parts.
- Be aware of unexpressed assumptions (e.g., normality, units, etc.).
- Verify that the data represents long-term variation. If data is not normally distributed, transform it.
- Do not get caught up in unwarranted minutiae.

3. Create a process sigma scorecard.

- Include sigma scores for all of the processes for building sub-assemblies and final assemblies (based on detailed process maps), and calculate the process capability to help you identify process improvement opportunities. Use statistical estimates to determine the defect levels of processes (measured in terms of parts, assemblies, and final product) and to measure the process behavior (i.e., the Voice of the Process, measured against process specifications).

Tip Use the following information as sources of information for this scorecard:

- Top-level and detailed process maps and flowcharts, with process capability data from models, Simulations, and workflow analyses
- Manufacturing design documents and specifications (from engineering departments) (Note: Include details on process data and assumptions from standard operating procedures and major component plans)
- CTQ process data for Critical to the Process parameters (Note: Include process prioritization tools, data from measurement systems and inspection points, and process capability data from existing quality systems)
- Manufacturing process database and past process records (Note: Include performance indicators for labor and material utilization, financial data, and outgoing defect data)
- Incoming defects.

a) Record the process step CTQ details.

- List the major and critical process steps for the final assembly.
- List the requirements/CTQs for each of the process steps.
- Assign metrics and units to each of the process step CTQs.

b) Record the Voice of the Customer data.

- For process step CTQs measured using variable data, obtain a target and specification limits. (Note: The specification limits might be one-sided.)
- For process step CTQs measured using attribute data, obtain the target defect level (usually 0).

c) Record the Voice of the Product data.

  - Denote the data collected as either LT or ST data.
  - Enter the observed mean and standard deviation or PPM defects for the measured process step.

d) Record the performance metrics.

  - Calculate Z USL, Z LSL, and DPU for each process step.
  - Calculate the RTY for each process step, using the equation:

$$\mathrm{RTY} = e^{-\mathrm{DPU}}$$

  - Calculate the total DPU for the process as the sum of the individual process step DPUs. Then calculate the overall process RTY using the equation:

$$\mathrm{RTY} = e^{-\text{total DPU}}$$

e) Interpret the information in the process sigma scorecard by asking:

  - Does our measurement system allow us to analyze all critical processes adequately?
  - What are the drivers for the current process performance scores?
  - What are the possible trade-offs to improve current performance?
  - How does the process sigma scorecard compare with the parts sigma scorecard?
  - Does the process sigma scorecard reflect the performance sigma scorecard results?
  - Are parts and processes interacting to produce a high number of defects?
  - Are our process sequencing assumptions valid?
  - Are the processes different? Which processes are best? Worst?

The Process Sigma Scorecard for a Treadmill

Process steps for final assembly	Parameter	Metric unit	Data type	Target	USL	LSL	LT/ ST	Mean	Std. dev.	Z USL	Z LSL	DPU	RTY
Attach motor to base	Tension	lbs.	Variable	8	8.5	7.5	LT	7.9	0.15	4.00	2.67	3.86E-03	100%
Attach console column	Height	in.	Variable	34	34.2	33.8	LT	34	0.08	2.50	2.50	1.24E-02	99%
Attach motor housing	Gaps	yes/ no	Attribute	0			LT					1.00E-03	100%
Attach handle bars	Visual	yes/ no	Attribute	0			LT					1.00E-02	99%
											Total	2.73E-02	0.9731

Note: This is a truncated version of a process scorecard, showing only the major process steps for the final assembly. All of the process steps in the manufacture and assembly of the product would be included in the full version.

Tip Use the information in the process sigma scorecard to:

- Determine the current quality levels of the critical processes.
- Estimate the effect of the design on manufacturing process performance.
- Analyze the required quality levels to realize product performance.
- Enhance data-driven communication among all stakeholders.
- Encourage design-for-manufacturability principles by bridging manufacturing and engineering.
- Combine various CTQ processes into a single score for comparison.

When using the process sigma scorecard:

- Use only critical processes prioritized using the QFD Matrix, Cause & Effect Matrix, and FMEA.
- Have top-level and detailed process maps for critical processes that include (at a minimum) specifications, current defect levels, product volume, labor and material requirements, and costing information.
- Remember that variable data requires fewer samples than attribute data.
- Perform measurement system analysis on the key metrics.
- When in doubt, consider the next process as the customer.
- Be aware of assumptions about the number of defect opportunities.

4. Create a software sigma scorecard.

- Include all of the steps in the software development process and compute the efficiency in each phase, to help eliminate defects in each stage of development.

a) Record the software CTQ details.

- List the software development process phases.
- List the requirements for each phase.
- Assign metrics and units to each of the software requirements.

b) Record the Voice of the Customer data.

- For software requirement CTQs measured using variable data, obtain a target and specification limits. (Note: The specification limits might be one-sided.)
- For software requirement CTQs measured using attribute data, obtain the target defect level (usually 0).

c) Record the Voice of the Product data.

- Denote the data collected as either LT or ST data.
- Enter the observed mean and standard deviation or PPM defects for the measured software requirements.

d) Record the performance metrics.

- Calculate the Z USL, Z LSL, and DPU for each software requirement.
- Calculate the RTY for each requirement, using the equation:

$$RTY = e^{-DPU}$$

- Calculate the total DPU for software as the sum of the individual requirement DPUs. Then calculate the overall software RTY using the equation:

$$RTY = e^{-\text{total DPU}}$$

The Software Sigma Scorecard for a Treadmill

Software development phase for treadmill console assembly	Parameter	Metric unit	Data type	Target	USL	LSL	LT/ ST	Mean	Std. dev.	Z USL	Z LSL	DPU	RTY
Requirements	Completeness	no. of incomplete	Attribute	0			LT					0.04	0.960789
Top design	Accuracy	no. of errors	Attribute	0			LT					0.03	0.970446
Program logic	Accuracy	no. of errors	Attribute	0			LT					0.012	0.988072
Data definitions	Accuracy	no. of errors	Attribute	0			LT					0.065	0.937067
Hardware interface	Compatibility	yes/ no	Attribute	yes			LT					0.016	0.984127
System test	Success	pass/ fail	Attribute	pass			LT					0.16	0.852144
Packaging	Accuracy	yes/ no	Attribute	yes			LT					0.08	0.923116
Documentation	Completeness	yes/ no	Attribute	yes			LT					0.4	0.67032
											Total	0.803	0.447983

Tip Develop the software sigma score estimates by:

- Using either attribute DPU or variable data.
- Selecting key metrics at each phase and computing defects (e.g., time to debug, number of reworks, design review attendance, etc.).
- Calculating the probability of software defects at each phase, based on historical data.
- Summarizing the DPMO for each software module and the overall DPMO.

Use information within this scorecard to:

- Determine the reliability of critical software components.
- Track defects in each major step of each software development phase.
- Compute your efficiency to detect and eliminate defects in each phase.
- Analyze the required quality levels to realize the cost-effectiveness and timeliness of the software development cycles.
- Encourage design-for-manufacturability principles by bridging design and delivery teams.
- Combine various CTQ processes into a single score for comparison.

When using the software sigma scorecard:

- Make sure that the scorecard contains all of the critical steps of the software development phases.
- Prioritize and apply the scorecard in critical areas first.
- Catch errors early and fix them as soon as possible. (The rework cost to fix an error at a later stage increases geometrically.)

- Include Software Engineering Institute (SEI) assessments (instead of defects per line of code), historical databases of defects, manuals, and defects data from field error logs and logs of customer calls, as good sources of information.

Tip When developing software:

- Adopt an efficient software development methodology.
- Do not hesitate to apply the design process to the software development process.
- Follow the SEI Capability Maturity Model (CMM) and operate at CMM Level 3 and above.

5. Develop the top-level scorecard.

a) Input the total DPU values obtained from each of the individual component scorecards.

b) Calculate total product DPU as the sum of the component scorecard DPUs.

c) Input the component scorecard sigma values and calculate the overall product design sigma value (using the information from the component scorecards and standard process sigma calculations).

Note: If you have generated multiple scorecards for various product assembly levels for the performance, parts, processes, and software, you can summarize the overall DPU and sigma levels in the top-level scorecard by including the total DPU from each scorecard you generated. Alternatively, you can generate an "intermediate-level component scorecard" that summarizes the information from the various product assembly levels for each of the four components and then subsequently summarize this intermediate-level information in the top-level product scorecard.

The Top-Level Sigma Scorecard for a Treadmill

Top-Level Scorecard

Treadmill	**Performance**		**Parts**		**Process**		**Software**		**Product Capability**	
	DPU	no. of opp.	DPU	no. of opp.	DPU	no. of opp.	DPU	no. of opp.	DPU	no. of opp.
Top level	0.429	4	0.0242	8	0.0373	5	142	3020		
Base assembly	0.959	1	0.0116	4	0.2138	4				
Totals	1.388	5	0.0358	12	0.2511	9	142	3020	143.67	3046
RTY	0.24957		0.96483		0.778		2.1E-62		4E-63	
Z LT	-0.6758		1.80976		0.7653		-5E+06		-5E+06	
DPU/opp	0.2776		0.00298		0.0279		0.04702		0.0472	
RTY	0.7576		0.99702		0.9725		0.95407		0.9539	
Sigma/Opp (Z LT)	0.6986		2.75009		1.9187		1.68565		1.6842	**LT Sigma**
Sigma/Opp (Z ST)	2.1986		4.25009		3.4187		3.18565		3.1842	**ST Sigma**

Tip Use the top-level scorecard to:

- Collect performance, parts, process, and software sigma scores in a single place to help locate problem areas.
- Determine the quality levels of the critical design elements.
- Estimate the defects you expect to find during transitions.
- Realize product performance by analyzing the required quality levels.
- Enhance data-driven communication among all stakeholders.
- Encourage design-for-manufacturability principles by bridging manufacturing, engineering, marketing, and information systems.

When evaluating the top-level scorecard:

- Start from the customer perspective.
- Consider cost in all design decisions.
- Include all processes, parts, and parameters that are critical customer requirements.
- Review the scorecard in standard design reviews.
- Use the scorecard system as a tool for improving the design, not as a grading system.
- Use DPUs (rather than sigma scores) to better understand a situation. (Sigma scores can mask issues.)
- Do not let the scorecard replace sound engineering and business judgment; use the scorecard to supplement existing tools.

Note: You may need to change some elements of the high-level design based on the Simulation, Prototyping, or Design Scorecard results. The results may require you to generate and test several alternatives by rerunning the Simulations or by building prototypes and retesting them.

When the Simulation, Prototyping, and/or Design Scorecard results indicate that the predicted design will meet the CTQs, document the final high-level design and complete all of the high-level design requirements.

Perform cost assessments to ensure that the cost of the design is within the acceptable range. Ensure that the risks associated with the design are identified and that risk management plans are developed as appropriate. "Freeze" the design requirements and conduct the high-level design review.

4.4.2 Review the high-level design

1. **Conduct a technical review of the high-level design.**
    - Evaluate the completeness and accuracy of the capability testing results to ensure that the design will meet the CTQs.
    - Identify critical areas of risk and actions to mitigate that risk.
    - Ensure that regulatory and legal requirements are satisfied.
2. **Conduct an organizational review of the high-level design.**
    - Identify and discuss any project management issues for the upcoming detailed design.

Note: Unlike the concept review, the high-level design review usually does not involve customers.

3. **Conduct a high-level tollgate review.**
   - Focus on:
     - The prioritized high-level design requirements.
     - Any designs on paper of the key elements.
     - Results from Simulation, Prototyping, and/or the Design Scorecard.
     - The cost/benefit analysis results.
     - The identification of high-risk areas and risk management plans.

The outputs of the high-level design review will include:

- A list of risk factors and action items, with owners and time frames identified.
- A list of additional analyses to be performed, if any.
- Dates for future high-level design reviews, if needed.
- A project plan for the detailed design.

This review can lead you to:

- Check the input data for prediction.
- Revisit the concept to see if changes are needed.
- Revisit the Multistage Plan and adjust what will go into each phase.
- Move to detailed design.

4.5 Identify and Prioritize the Detailed Design Elements

The process to identify and prioritize the detailed design elements is similar to the process for the high-level design elements, but is at a greater level of detail. Use the same element categories that you did for the high-level design (i.e., products/service elements, information systems elements, human systems elements, etc.) but design them to the next level of detail.

> ***Tip*** As you move from high-level design to detailed design, be careful not to make the creative system-level decisions at the detailed design stage that you made in the concept or high-level design stage; instead, make very specific decisions on the design elements that you already selected. Understand how these decisions fit together and how to manage the project to allow the diverse parts of the design to come together at the right time and at the right cost.

How do I do it?

1. **Identify the detailed design elements.**
    - Define the high-level design elements to the next level of detail, to identify the specific elements and requirements for the detailed design. Choose:
        - The specific vendors, programs, hardware products, training packages, hiring agencies, etc., that you will need to complete the design development.
        - The process and input variables (process control variables) that you will measure and monitor to ensure that the service performance is under control.

For example, the detailed design equipment category for our order placement process might include:

Element descript.	High-level design	High-level requirements	Detailed design
IVR hardware	• An open, scalable, standards-based framework that forms a unified foundation for customer interaction and enables the real-time integration of diverse media types, including phone, fax, email, and the web, with the ability to accommodate emerging interaction mediums in the future • A broad suite of call center applications including inbound and outbound communications routing and reporting that sit on top of the framework	• Able to handle up to 100 agents • Skill-based routing with up to twenty skill codes • ACD handling up to ten voice/fax calls in queue • Router speed of 0.36 seconds/package	Supported third-party applications: • Enterprise Resource Planning (ERP Resource Suite) • Customer Information Systems (Inforsyst, Inc.) • Sales Force Automation (Inforsyst, Inc.) • Performance Monitoring (pmdsystems .com) Supported network operating systems: • Computernet Cosmos • Webnetport IV Switch: • Pakin Hicomm • ATPS 6FQ13 • Belmont 1000 Supported desktop integration standards: Port Collector 9, Wildcat, Ultradeck EQ

2. **Determine which detailed design elements and process control variables are most important.**

   - The most important detailed design elements are those that impact the most important high-level design elements. The most important process control variables are those that should be monitored carefully because they are usually the leading indicators of deteriorating process performance.

- Create a QFD Matrix (QFD 4) with the high-level design elements in the rows and the detailed design elements and/or process control variables in the columns. (Note: For product designs, you may need to create a separate QFD Matrix for each high-level design element because of the many components for each high-level element.) For each element/function relationship, ask, “To what extent does this detailed element impact the performance of this high-level element?” Use the 9, 3, 1 scale and matrix multiplication to help you prioritize the elements.

  Note: It is also appropriate to enter the high-level design *requirements* in the rows of the matrix. Typically, at this stage, the decisions to choose specific pieces of software or hardware are based upon the requirements (i.e., to what extent does the selected product meet the requirements for the design).

Tip For designs that you will develop yourself, the importance ratings of the detailed design elements help to show where you should spend the most time in development. For designs that use commercial software or hardware purchased from a third party, the importance ratings help to determine where to place the greatest effort in evaluation and where to focus your integration efforts.

Prioritizing the detailed design elements for our order placement process could result in the following QFD Matrix:

QFD Matrix for the Detailed Design Elements

Detailed Design Elements **High-Level Design Elements**	Phone network hardware X	IVR hardware Y	Order processing system Z	Average order volume/day	Percentage of complex orders	Percentage of customers dropping out of IVR	Percentage of orders with errors	Importance (from QFD 3)
Order placement process					9		9	89
Fax and phone network	9			9				57
IVR hardware/ software		9	9	9			3	52
Order processing system			9	3			3	52
Order processing agents				9	9	9	9	49
How important	113	468	468	1110	1242	491	1398	

Note: Although this QFD Matrix combines the detailed design elements and the process control variables, this combination may not always be possible. You may need to separate the two types of variables, depending on the complexity of the problem.

In this example matrix, the input variables (the percentage of orders with errors, the percentage of complex orders, and the average order volume per day) are more important than the design elements (the hardware or software purchased); it is therefore critical to design a robust process control system.

4.6 Develop the Detailed Design

Note: As you proceed from theoretical design to actual development, the design activities may take quite a bit of time, depending on the complexity of the detailed design process. The actual time necessary will depend on how much development work you need to do.

How do I do it?

1. **Complete the design of all of the supporting elements.**
   - You may use other design methodologies (e.g., standard software design methodologies) to develop the various elements of the design and to provide the details for each element and the associated deliverables.
2. **Ensure that you have included all of the elements of the design and that no gaps remain.**
   - Make sure that all of the necessary aspects of the design have been handed over to sub-teams.
3. **Make sure that the design schedules can accommodate the design and the integration of the various elements.**
4. **Ensure that good communication exists between the design sub-teams.**
   - Communicate frequently to ensure that the design is proceeding smoothly and on schedule.
5. **Use design principles to guide the design process.**
   - Develop specific deliverables for each element category and for the prioritized high-level and

detailed design elements. Consider the following principles when addressing each category:

Category	Deliverables	Principles (Consider design features that:)
Product elements	• Descriptions and drawings • Legal and regulatory impacts • Models and prototypes • Specifications	• Transform the product to something better or more desirable • Distinguish the product or service • Create more value to the customer • Make the product or service expandable
Process elements	• Proces flowcharts • Process deployment maps	• Focus on interactions with the customer (i.e., the "moments of truth") • Minimize rework • Minimize or eliminate inefficiencies or non-value-added activities • Minimize inspections • Minimize variability • Minimize hand-offs • Minimize potential errors/failures
Information systems elements	• A logic design • A physical design • A hardware design • Test plan/software scripts • A data migration plan • Test and production environment • A description of the facilities needed	• Obtain current and on-going customer feedback • Make appropriate information accessible at the workplace • Automate the collection, storage, and transfer of information • Clarify what information is needed, when it is needed, where in the process, and by whom • Ensure that there is timely and easy access to the information
Human systems elements	• Job/task analysis • Ergonomic analysis • A training design • Reward and recognition plans • An organizational design	• Organize around work processes • Assign responsibilities for complete processes • Move decision making to the workplace

Continued on next page

Category	Deliverables	Principles (Consider design features that:)
Human systems elements (continued)	• Employee development plans	• Enlarge and enrich jobs • Match jobs with skill levels • Identify and nurture core competencies • Create an environment for intrinsic motivation • Provide an opportunity for career growth
Equipment	• Descriptions and drawings • Specifications	• Minimize fixed investments • Automate routine work • Ensure the reliability and maintainability of necessary equipment
Materials/ supplies	• A bill of materials • Forms designs • Purchasing and inventory impacts	• Minimize inventory • Maximize inventory turnover • Form partnerships with suppliers
Facilities	• Architectural drawings • Scale models • Computer models • Layout diagrams	• Combine centralization and decentralization • Minimize motion and distances traveled • Organize the workspace in the appropriate sequence of the work process • Consider ergonomic issues such as lighting, proper body mechanics, fatigue, morale, and distractions • Prevent injury • Consider person/ machine interactions

Note: These design principles are more specific than the ones used in the high-level design in that they pertain to each element of the design.

4.7 Test the Detailed Design

Because you tested the high-level design before moving on to the detailed design, it is not necessary to test all of the pieces of the design again. Instead, test only those parts of the design that are vulnerable to failure.

To test the vulnerable parts of the design:

1. **Identify the points of vulnerability.**
   - Consider:
     - New or untested technology.
     - Transition points, especially to and from manual processes.
     - Customer "moments of truth."
     - Parts of the design that are susceptible to significant input variability (based on data from the process management system; for new designs that may not have process management systems in place yet, use data from Simulations, research, benchmarking, or technical knowledge).
     - Parts of the design that are susceptible to catastrophic failure (based on the past experience of subject matter experts).
2. **Test the points of vulnerability using Simulation, FMEA/EMEA, and/or Design Scorecards.**

Note: If you uncover performance gaps in this testing, develop potential solutions and repeat the capability testing until you achieve acceptable results. Once the detailed design is tested, use FMEA/EMEA to identify and address any remaining significant risks.

What is it?

The Failure Mode and Effects Analysis or Error Mode and Effects Analysis identifies the points in a process where problems might occur, provides a numerical score for these potential problems, and helps you decide which actions to take to avoid such problems.

Note: An FMEA assesses product, component, or system failures. An EMEA assesses processes in which the primary failures are human errors.

Why use it?

- To identify high-risk areas where a process, product, or service might fail
- To help develop action plans to prevent the causes of those failures
- To make a process robust enough so that the causes of potential failures will not affect it

How do I do it?

1. **List the steps of a process (or the components of a product if you are creating a product design) in the left-hand column of a matrix.**
2. **For each process step or component, list potential failure modes or ways in which the process, product, or service might fail.**
3. **List the potential consequences or effects of each failure (e.g., defective product, wrong information, delays, etc.) in the matrix and rate the severity of each consequence on a scale of 1–10.**

   Tip There can be multiple failures for each step and multiple effects for each failure. Score each separately.
4. **List the potential causes of the effects and rate their likelihood of occurrence on a scale of 1–10.**
5. **List the controls that you currently have in place for the process and rate your ability to detect each potential cause on a scale of 1–10.**

   Tip Develop your own scales for severity, occurrence, and detection, or use the sample scales shown on the following page.

Sample Severity, Occurrence, and Detection Scales

Severity = Likely impact of the failure

	Rating	Criteria: A failure could . . .
Bad	10	Injure a customer or employee
	9	Be illegal
	8	Render the product or service unfit for use
	7	Cause extreme customer dissatisfaction
	6	Result in partial malfunction
	5	Cause a loss of performance likely to result in a complaint
	4	Cause minor performance loss
	3	Cause a minor nuisance; can be overcome with no loss
	2	Be unnoticed; minor effect on performance
Good	1	Be unnoticed and not affect the performance

Occurrence = How often the cause will occur

	Rating	Time Period	Probability	
Bad	10	More than once per day	>	30%
	9	Once every 3–4 days	<	30%
	8	Once per week	<	5%
	7	Once per month	<	1%
	6	Once every 3 months	<	.03%
	5	Once every 6 months	<	1 per 10,000
	4	Once per year	<	6 per 100,000
	3	Once every 1–3 years	<	6 per million
	2	Once every 3–6 years	<	3 per 10 million
Good	1	Once every 6–100 years	<	2 per billion

Detection = How likely we are to know if the cause has occurred

	Rating	Definition
Bad	10	Defect caused by failure is not detectable
	9	Occasional units are checked for defects
	8	Units are systematically sampled and inspected
	7	All units are manually inspected
	6	Manual inspection with mistake-proofing modifications
	5	Process is monitored via statistical process control (SPC) and manually inspected
	4	SPC used, with an immediate reaction to out-of-control conditions
	3	SPC as above, with 100% inspection surrounding out-of-control conditions
	2	All units are automatically inspected
Good	1	Defect is obvious and can be kept from affecting customer

6. **For each row, determine the risk of each failure mode by multiplying the severity x the occurrence x the detection in the row. Record the result of this calculation as the risk priority number (RPN) in the matrix.**
7. **Identify recommended actions to reduce or eliminate the risks associated with high RPNs and list the actions in the matrix.**

   Tip You can recalculate the RPNs for any failure mode after you determine which action you will take to avoid those failures.

Note: The example on the next page combines failure modes and error modes in a single chart. This type of combination can be appropriate if the risks associated with the two modes are not significantly different and can be compared to each other.

The FMEA analysis in this example is also at a high level of detail. More typically, an FMEA is conducted on just one part of the process, but at a greater level of detail; in such cases, you may need to create a larger, more complete FMEA.

A Sample FMEA/EMEA Chart from the Order Placement Process

Item/ Process Step	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) of Failure	Occurrence	Current Controls	Detection	RPN	Recommended Actions
Order entry	Customer cannot place order	Customer is dissatisfied	7	Telephone network is dead	5	Telephone company provides notification	1	35	Current control is adequate
	Customer cannot place order	Customer is dissatisfied	7	Network is overloaded because of unexpected call volume	8	No current controls (process does not exist)	10	560	Monitor average speed of answer automatically; provide warning if above limit
Order processing	Customer's order is not recorded	Customer does not receive ordered item	7	Order recording system is down	6	Periodic system monitoring	8	336	More systematic monitoring
	Customer's order is incompletely or inaccurately recorded	Customer receives wrong items	6	Order entry data is incorrect	9	No current controls	10	540	Introduce passive validity checks as much as possible
Order validation/ confirmation	Order not validated	Customer doesn't have proof that order is complete	5	System is not working	6	Periodic system monitoring	8	240	More systematic monitoring
	Order confirmed in error	Customer is misinformed	6	Communication problems between catalog systems and order entry system	4	No current controls	10	240	To be detemined
Order transmission	Order not transmitted	Customer does not receive items	7	System is not working	6	Periodic system monitoring	8	336	More systematic monitoring
	Order transmission hung	Customer does not receive items	7	Communication problem	4	Can be detected	1	28	Current control is adequate

4.8 Develop the Process Management Plans

A process management plan is a well-defined plan of action for monitoring processes in the context of the entire organization. The plan helps to manage the process "end-to-end," focuses on actionable steps and integration with day-to-day management, and helps to ensure that the design will continue to meet the CTQs over time.

The process management plan can also help you collect and analyze data during the pilot. You will use the same framework to collect data during the pilot that you will use to collect data after implementation because the types of data collected and the analyses conducted are the same in both situations.

Note: Obviously, process management plans are necessary when designing a process or service, but you will also need process management plans for product designs, to manage the processes and services that make and support the product.

> ***Tip*** Your organization may already have a process management approach defined and in use. Use your organization's current process management approach if appropriate.

To develop a process management plan:

1. **Determine the structure and composition of the process management team(s).**
   - Ask:
     - Who are the team members?
     - What functions will they serve on the team?
     - Who are the permanent and rotating members?
     - Who is the team leader?

    - How often does the team meet?
    - What is the structure of the process management team meetings?
- Include process owners who will be impacted by the implementation of the design project and communicate with them regularly throughout the design process. You may need to include teams of process owners to ensure that the system that supports the new design will continue to operate as expected.

2. **Document the key processes of the process management plan.**
    - Ask:
        - Are all process flows at the appropriate level?
        - Are there clearly articulated links between high-level and low-level documentation?
        - Have methods and procedures been created from low-level flows?
        - Are document control plans in place to change obsolete material?
        - Do the key processes follow corporate documentation standards?
3. **Determine the critical metrics for monitoring performance.**
    - Consider:
        - What key CTQs need to be monitored.
        - What the relationships between the CTQs and critical process and input measures are.
        - If the definitions of all metrics are complete and documented.
        - If the measures focus on both leading and lagging indicators.

  - If the measures are actionable and easy to understand.
  - If customer satisfaction and employee satisfaction measures have been linked to the CTQs.
  - If learning and growth measures are included.

4. **Define the data collection, analysis, and reporting plans.**
   - Ask:
     - How should we collect the data required for reporting?
     - Is any manual data collection needed?
     - How often should we collect the data?
     - What is the sampling plan for data collection?
     - What tools are needed to analyze the data?
     - What display formats will we use?
     - What is the structure and content of the performance reports?
     - Who receives the performance reports and how often?

5. **Create an intervention and process improvement plan.**
   - Ask:
     - What action plans need to be in place to address performance issues?
     - What is the follow-up process to ensure that action plans have been implemented?
     - What are the triggers to initiate intervention strategies?
     - How is process management integrated with our design and improvement cycles?

- How do we deal with common cause or special cause variability?
- Does it feed into the process management approach?

Use a Process Management Chart (also known as a QC Process Chart) to communicate information about processes to your organization and track process progress. Also use a Process Management Chart to collect and analyze data during the pilot. Include the CTQs and the process and input measures related to the CTQs in your chart.

What is it?

The Process Management Chart summarizes the key information a process owner needs to effectively monitor and control a process (including the type of corrective action to take in response to signals from the measurement system).

Why use it?

To ensure that process owners in the organization have the information they need to maintain and control the design once it is implemented

How do I do it?

1. Create a chart with three columns: a "Plan/Do" column, a "Check" column, and an "Act" column.

2. Use a flowchart to fill in the Plan/Do column of the chart.

- Capture the essential steps of the process you designed. For each key step, show how the operation should be done or provide a reference to a document that describes the step.

Tip Use a Deployment Flowchart to document processes that flow across departments or areas. Use an Activity Flowchart to document processes where work is performed by one person or group.

3. Complete the Check column of the chart.

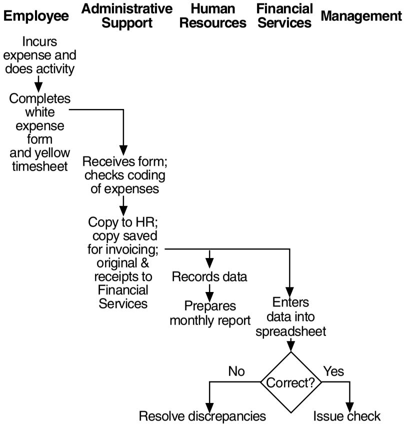
- Describe when and how you will collect data to monitor the processes and their outputs, (e.g., elapsed time, completeness, errors, or temperature).
- For each key process indicator, describe any important targets, tolerances, or specifications to which the process should conform if it is running well (e.g., eight hours from receipt, all boxes checked, 125°F–135°F). Use targets or specifications defined by customers, regulatory policies, or process knowledge as these standards.
- For each key process indicator, describe how the monitored data should be recorded (e.g., on a Checklist, Run Chart, Control Chart, or Scatter Diagram). Describe, if necessary, who will record the data and how.

Tip For manufacturing processes, describe any technical specifications that you have to meet. For administrative and service processes, describe the quality criteria defined for the process.

4. Complete the Act column of the chart.

- Describe how process owners or operators should react, depending on what they find as they measure the process.
- Address what you will do to control any damage that may occur in the process. Ask:
  - Who should do what with the output of the defective process?
  - What should be done for customers who receive the defective output?
  - What adjustments should we make to ensure that the defects do not occur again?
- Address the procedures you will use for any necessary process adjustments. Ask:
  - What must we do to gain sufficient understanding of this process so that we know what adjustments and accommodations are routinely necessary to prevent a recurrence of this problem?
- Address the procedures you will use for process improvement.
  - Who in the organization needs what data in what form to be able to make sound decisions regarding new systems or remedies at deeper levels in the organization (i.e., changes in basic designs or policies)?

A Sample Process Management Chart

Plan/Do	Check	Act
Flowchart	**Key Process Indicators**	**Corrective Actions**
	100% inspection for standards: 1. Received by 5 p.m. Tues. (on-site) or 5 p.m. Wed. (by mail). 2. Operational definitions of expenses used. 3. Complete information provided. 4. Columns added and summary completed.	Correct form or return to employee. Discuss corrections with employee. Provide training if needed.
	Receipts behind form, stapled in upper left corner.	Correct form or return to employee. Discuss corrections with employee. Provide training if needed.
	HR does 100% inspection for proper use of time-coding vacation, leave, and holiday expenses used.	If unclear about budget codes, check with manager.
	FS responsible for: 1. All charges allocated. 2. Proper use of budget codes.	If incorrect: 1. Work with Administrative Support to resolve. 2. Track common areas of problems and report to manager monthly.

Once you have identified the process owners who will have ongoing responsibility for implementing, monitoring, and improving the design, update the change plan:

- Identify any new stakeholders (in operations management) and do a stakeholder commitment analysis.
- Review and update the communication plans.
- Integrate the organizational change plan with the pilot and implementation plans.

4.9 Review the Pre-Pilot Design

The pre-pilot design review is the last of many technical reviews conducted during the detailed design phase. It:

- Ensures that all of the elements of the design are complete.
- Ensures that all of the designed elements are well-integrated and that interfaces between different parts of the design are completely seamless.
- Identifies possible failure points and areas of vulnerability to be tested in the pilot.
- Reviews the pilot and implementation plans.
- Reviews the process management plans.

Note: Unlike the concept review where all interested parties are allowed to comment on the design, the pre-pilot review is usually restricted to technical discussions.

Because the design is more complex at this stage, the design review process itself becomes more complex.

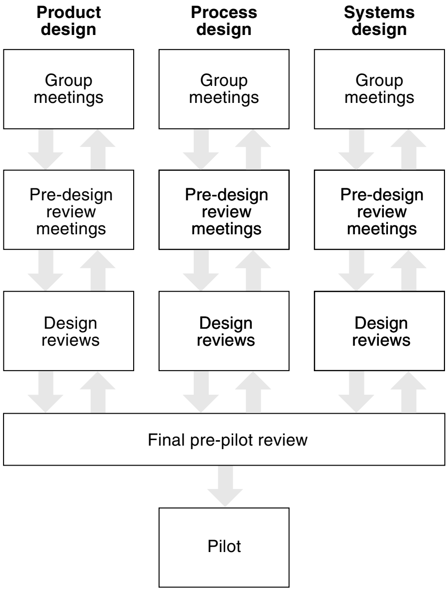
For each critical design element, there may be multiple meetings before the final design review takes place, including (in sequence):

- Small group meetings to allow groups to review individual parts or modules of the design.
- Preliminary design review preparatory meetings to collect and review all necessary documentation, ensure consistency and completeness in analysis and reporting, and work on problems or issues that may affect the design review.
- Formal design review meetings.

After you review the designs for the individual elements, conduct a final pre-pilot review to inspect the overall design and to review the pilot plans and implementation plans before launching the pilot.

Note: All of the steps in the pre-pilot design review include feedback loops. Based on the results of the design review for a particular element, you may need to conduct another of series of preparatory meetings to address issues before you schedule the final pre-pilot review. Similarly, findings from the pre-pilot review may suggest corrections to the design of one or more elements (which will need to be reviewed again) before you can launch the pilot.

Feedback Loops in the Pre-Pilot Design Review



To keep the review process effective:

- Establish the review objectives and agenda in advance.
- Complete all pre-work in preparatory meetings.
- Keep the documentation clear and consistent.

- Index the documentation to make it easy to find and reference.
- Distribute the documentation in advance of the meeting.
- Set up follow-up procedures for confirming the completion of identified action items.

A successful design review requires preparation and planning. More than at any other stage in the design process, the consistency, accuracy, and readability of the documentation for this review can seriously impact the quality of the pre-pilot design review.

Give the participants enough time to read the documentation before the review session itself. Ask participants to submit questions in advance so that the design review process can flow smoothly. Also, clearly state the objectives of the review and ensure that they are understood by all parties so that there are no digressions or diversions that may impact the review's effectiveness.

Documents to use in a pre-pilot design review include:

- A description of the design, which could include models, prototypes, blueprints, diagrams, and specification lists.
- A description of all design tests and results, including Simulations, trial runs, FMEAs/EMEAs, and any other tests conducted on the design. (Be sure to provide all of the results with adequate supporting documentation and place special emphasis on identified high-risk elements or failure points.)
- A description of the range of conditions under which you will test the design, including details of how the pilot will test the design under these conditions. (Detail the legal and environmental issues that may impact the performance of the design as well.)

The output of the pre-pilot design review will include:

- A list of participants.
- A list of key issues raised, identifying who raised them.
- A list of proposed actions, including who is responsible for each action.
- A list of changes to reviewed documentation.
- A schedule of future meetings to assess the completion of proposed actions.
- A schedule of future design review meetings, as appropriate.

Completing the pre-pilot design review could lead you to:

- Redesign one or more elements of the design and move to the pilot.
- Redesign one or more elements of the design and schedule another design review.
- Move to pilot planning.

Clearly, the first two options apply if the design review indicates that there are issues with one or more elements of the design or if the design elements do not fit together. If you have not adequately prepared prior to the design review, you may find yourself faced with the second option, which will usually delay the launch date of the product or service. While this is still better than discovering errors after launch, this option is less efficient than the first option and could result in significant customer dissatisfaction due to the delay.

Note: For further information and examples of design reviews, refer to *Product Design Review—A Method for Error-Free Product Development*, Takeshi Ichida (ed.), Productivity Press, Portland, Oregon, 1996.

4.10 Hold a Tollgate Review

Note: For general information on tollgate reviews, see section 1.5 in the Define step.

The tollgate review for the Design step focuses on:

- The developed design.
- Completed Simulation or FMEA/EMEA analysis.
- Design solutions for vulnerable elements.
- Organizational change plan updates.
- Process management system variables and details.
- Plans for the pilot.

This tollgate review can lead you to:

- Redesign one or more elements.
- Look for alternate vendors if the chosen vendors do not provide the necessary results for the design.
- Improve the process management and/or pilot plan.
- Increase the duration of the pilot.
- Implement the pilot as planned.

How do I do it?

1. **Update the Storyboard.**
2. **Review the Tollgate Review Form used at the end of the Analyze step. Revise and answer the specific questions that describe what was done in this step and what you need to do in the next step.**

The Design Tollgate Review Form

Design:
Develop the design
and prepare
for the pilot

Deliverables:

❑ Tested and approved high-level design
❑ Tested and approved detailed design
❑ Plans for process control and pilot
❑ Completed design reviews
❑ Updated Storyboard presentation
❑ Updated project plan

- What are the prioritized key elements of the design?
- How do the elements relate to meeting the CTQs?
- How was the design tested? What were the test results?
- How did you involve customers in the design evaluation?
- How did you identify vulnerabilities in the design? What were the vulnerabilities and how are you addressing these?
- What is your plan for conducting a pilot?
- What limitations or barriers have you encountered?
- Review your project plan: are you on track?
- What are your key learnings from the Design step?
- What are your next steps?

3. **Present a progress report at the tollgate meeting using the Tollgate Review Form. Discuss the report and any issues; ask and answer questions about data and logic.**
4. **Identify the strengths and weaknesses of the project so far.**
5. **Decide on next steps.**
6. **Identify the strengths and weaknesses of the review.**

Why do it?

To pilot and test the prototype, implement the final design, and close out the team.

Tools used in this step:

- Planning tools
- Data analysis tools:
  - Control Charts
  - Pareto Charts
- Standardization tools:
  - Flowcharts
  - Checklists
- Process Management Charts

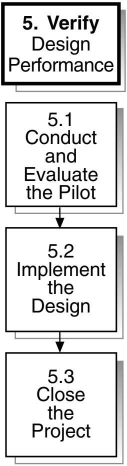
Outputs of this step:

- A working prototype with documentation
- Plans for full implementation
- Control plans to help process owners measure, monitor, and maintain process capability
- A transition of ownership from the design team to management and the process owners/operators
- Completed project documentation and project closure
- A final tollgate review and updated Storyboard

Key questions answered in this step:

- How do we ensure that the pilot is realistic and produces meaningful results?
- What actions must we take if the performance of the pilot is unsatisfactory?
- How do we ensure that we can sustain the performance of a successful design over time?
- How do we reward the design team and celebrate their accomplishments?
- How can we share the lessons learned by the design team with the entire organization?
- How can we make sure that the organization embraces and supports the changes resulting from the design?

How do I do it?



5.1 Conduct and Evaluate the Pilot

1. **Use the Plan-Do-Check-Act (PDCA) Cycle as you conduct the pilot.**

Note: The implementation of a typical design will proceed through one or more turns of the PDCA Cycle. The initial turn is the pilot, which often leads to one or more improvement activities prior to full-scale implementation.

- Make careful observations of all activities, effects, and interactions during the pilot. Be sure to continue the pilot long enough to establish reliable baseline performance data.
- Pay close attention to the Check step of the PDCA Cycle when conducting and evaluating the pilot. Be sure to:
  - Check both the pilot plan and the results.
  - Compare the plan to what actually occurred. Ask:
    - What changes in schedule occurred? Why?
    - Were instructions followed? If not, why?
    - How well did training and communication prepare people for the pilot? What improvements are needed to prepare them for full implementation?
    - Were processes and procedures adequately documented? What checklists, visual cues, or

job aids would have helped? What improvements are needed?

- What unexpected barriers, issues, or rework occurred? What may have caused these problems? What remedies were tried? How successful were they? What improvements are needed?

Tip Pilots for complex projects should typically be 12–16 weeks long. Pilots for less complex projects should be 6–8 weeks long. Be sure to allow the process to stabilize for the first 2–3 weeks before collecting data.

Caution: Even a small process change can affect many other processes. Make sure the design does not cause problems for internal supplier and/or customer processes. Inform people in areas such as planning, inventory, facilities management, and quality control of any changes to allow them to adjust their work where necessary, and check administrative processes in personnel, finance, or accounting departments for unforeseen consequences.

2. **Use the pilot to check your process documentation.**
   - Ask:
     - Are all procedures written clearly?
     - Is the process standardized at the right level of detail?
     - Can people follow the standards?
3. **Use the pilot to check your plans for ongoing process management once the design is fully implemented.**
   - Ask:
     - What did we learn from the data collection during the pilot that will improve ongoing data collection for process management?

  - When problems occurred during the pilot, was it clear to participants what actions to take? Could they take those actions?
  - Do we need to update the process management plan?

4. **Use the Check and Act steps of the PDCA Cycle as a bridge between the pilot and full-scale implementation, and between implementation and ongoing process control.**

   - Compare the pilot results to the CTQs:

- Did all of the elements of the design perform as required? If not, why? What might have caused the variation?	*Check* step
- Is performance acceptable? How satisfied were pilot customers with the performance?	*Check* step
- If the pilot results are good, capture the learnings and prepare for full-scale implementation.	*Act* step
- If significant gaps are identified, conduct a root cause analysis to understand why.	*Act* step
- After modifying the design to address the root cause(s), consider conducting another pilot.	*Act* step
- Document all of your results, procedures, and learnings.	*Act* step

   - Be sure the organization can consistently achieve the results *because of* the design and not just occasionally *in spite of* the design due to heroic efforts.

Caution: Make sure that people are following the designed procedures; otherwise, the results of the pilot may not be the results of the design.

5. **Perform a pilot review.**
   - After you complete the pilot and analyze the data, review the results with management. Focus on:
     - Reviewing the analysis of pilot results (and re-pilot results as appropriate).
     - Discussing the problems identified during the pilot, causal analysis (identification and verification of the root cause[s]), and data on the effectiveness of countermeasures taken.
     - Reviewing any risk issues.
   - Review the performance of the pilot as compared to targets with key implementation managers/process owners and the team. Present data about the results and the plan. Present causal analysis along with proposed (and possibly tested) countermeasures. (At this point, there should be no "red light" risks and few moderate risks.) Create contingency plans for any remaining risks.
   - Discuss how well the communication and other organizational change strategies prepared participants in the pilot for their responsibilities.
   - Highlight what it will take to help the rest of the organization embrace and implement the new design. Review the current perspectives of stakeholders whose support is important to the design's success, along with plans to close any critical gaps.

   The results of the pilot review could lead you to:

   - Approve the design for full implementation and update any organizational change plans.
   - Request a redesign and retesting of all or parts of the design, along with another review.

Tip Use daily performance reviews when starting up the pilot and when you start up each stage of implementation; reduce their frequency as appropriate. Determine how you can:

- Have additional resources available to troubleshoot problems.
- Manage the expectations and perceptions of customers, management, staff, and stakeholders.
- Actively manage your implementation plan.
- Celebrate your successes.

6. **Verify the design's success.**

   Verifying a design's success is one of the last steps before making significant, sometimes irreversible investments. Make sure that everything is in order before moving on to full implementation of the design. Ask:

   - Is the process, product, or service meeting the performance requirements?
   - Are all process steps documented for a smooth transition?
   - Did we encounter implementation issues that we did not previously consider?

   Tip If you have validated and verified the design goals, you can then begin planning for full-scale implementation; if not, you should continue to use the PDCA Cycle until the design goals are met.

5.2 Implement the Design

Make sure that you involve other organizational leaders in reaffirming organizational ownership and responsibility for the full implementation of the design. A broad understanding and support for the design team's boundaries is necessary for the transition to implementation to proceed smoothly.

> ***Tip*** Although the charter initially defined the full-scale implementation, you may have refined this definition in the Multistage Plan as the design evolved. Be sure to revisit prior agreements about the boundaries of the implementation so that the design team knows when its work is complete.

To implement the design:

1. **Select the implementation strategy.** ***Plan* step**
2. **Develop the implementation plans.** ***Plan* step**
3. **Update the documentation for procedures.** ***Plan* step**
4. **Update the process management plan.** ***Plan* step**
5. **Update the implementation plan FMEA/EMEA.** ***Plan* step**
6. **Carry out the implementation.** ***Do* step**
7. **Review the implementation.** ***Check*/*Act* steps**

5.2.1 Select the implementation strategy

How do I do it?

1. **Identify how you will implement the design in different locations or areas.**
    - You can implement the design:
        - In sequence (i.e., implement the design in one location before starting the next location).

- In phases (i.e., partially implement the design at one location, then start a second location).
- All-at-once (i.e., start all locations simultaneously).

You can also combine these approaches.

To help you decide which approach to use to implement the design, consider:

- What resources the approach will need.
- How it will affect ongoing work and your ability to meet commitments.
- How long it will take to complete the implementation.
- How it will affect other initiatives that are under way.
- What technology issues you will encounter as you implement this approach.

5.2.2 Develop the implementation plans

How do I do it?

1. **Create detailed work plans.**
    - Use the pilot plans as the foundation for the detailed work plans.
    - Include all of the tasks needed to bring the new process, product, or service up to full capability.
    - Incorporate scale-up plans (for issues that will arise when moving from a limited trial to full-scale implementation) and improvements from the pilot.
    - Have the people involved in the implementation participate in creating the plan so it is tailored to their situation.

- Include opportunities for employees in different areas to customize the plans for their particular environment. (Participation in tailoring the plans encourages support from a broad base of employees, and this support is needed for a successful design.)
- If necessary, use subplans for each design element (e.g., a facilities implementation plan, an information systems implementation plan, etc.).

2. **Create a transition plan if the new design will replace existing work processes, equipment, or facilities.**

   - Minimize the disruption that the new design could cause by creating a plan to facilitate the transition to the new design. Describe how the organization's ongoing work will be handled while the new design is being installed. Common approaches to minimize disruption and transition the work include:
     - Shutting down the current location and transferring the work elsewhere until the changeover to the new system is complete.
     - Running both old and new systems in parallel until the new system is stable.
     - Using rapid methods for transferring work from the old system to the new system during low capacity times.

3. **Update the training plan used in the pilot.**

   - Include:
     - A list of the information that you need to share.
     - A plan to develop the materials used in training.
     - A description of the audience for the training and an assessment of their training needs.
     - A plan for how you will spread the training to the appropriate people in the organization.
     - A plan to test the effectiveness of the training.

Carefully coordinate the training plan to coincide with the rest of the implementation plan. Include relevant process maps, procedures, and documentation. (Update and prepare the standard work practices prior to the beginning of training.) Also remember that you may need ongoing implementation support or a help desk to supplement some training situations.

Check the training plan for completeness. Ask:

- What steps or activities will change as a result of the new design?
- Who performs these steps or activities? What is the best way to prepare these people to do the work to support the new design?
- Is training needed? If so, what materials do we need?
- Who can conduct the training? What preparation will they need?
- When will we deliver the training? Where?
- How will we follow-up or support the training?
- How will we evaluate the training?

4. **Update the communication plan used in the pilot.**

    - Include:
        - An explanation of the business case for the new process, product, or service.
        - A report on the pilot and what made it successful.
        - A "What's In It For Me?" analysis.
        - A description of how company leadership will support the effort.
        - A review of the implementation and training plan.

While ongoing communication is important throughout the design, pay special attention to how you plan to communicate the implementation of the new design to the organization, to customers, and to stakeholders outside of the organization.

Closely coordinate the timing of the communication plan with the implementation plans so that customers do not expect the new process, product, or service before it is available, and investors do not expect to see the results from the new process, product, or service sooner than is reasonable.

5. **Form implementation teams at each location.**
    - These teams will help:
        - Adapt the draft implementation plan to their location.
        - Carry out the implementation at their location.
        - Help employees at the location change work habits and methods to support the new process, product, or service.
        - Report progress and problems to management and to the design team (until the design team is closed).

5.2.3 Update the documentation for the procedures

How do I do it?

1. **Update documented standard operating procedures (based on the results of the pilot) and distribute the updated procedures.**
    - Include flowcharts, drawings, schematics, written instructions, and cautions.

- Make sure that documentation is at an appropriate level of detail (i.e., it is specific in telling precisely what actions to take and when and where to take them). Make sure it describes how to prevent variation (i.e., it describes underlying cause-and-effect relationships) and focuses on priorities.

  Note: Documentation may be written, photographed, illustrated, or on video or audio tape.

- Record what to do and why, in language that is simple enough for most people unfamiliar with the job to follow and produce the desired results.

Tip You will likely need documentation for each design element (e.g., documentation for sales, order processing, manufacturing, shipping, customer service, technical support, etc.).

- Store the documented standard operating procedures so that:
  - Everyone has easy access to the information.
  - You can easily update them.
  - You can easily control versions of the documentation.
  - You can have links between documents.
  - People who are not fully trained can easily use them.

Tip Many organizations already have standard methods in place for documenting detailed work procedures. Use your organization's standard methods, if possible.

Sample Documentation for an Order Entry Process

Sales Dept.		**Operational Documentation**	Page 1 of 1	Picture - Flowchart - Drawing - Form - Etc.
Process Analysis Worksheet				
Date: March 2		**Process:** Order Entry/Phone	**Owner:** Judy/Sales	
Step	**Major Step**	**Key Point**	**Special Instructions**	
	Take order by phone	1. Use order form	1. In file rack – First slot	
	Complete form	1. Customer information	1. Customer key number – Date – Initials of order taker	
		2. Payment method	2. Purchase order number – Credit card information – Tax status	
		3. Marketing information	3. Buyer's name – How they heard about the product – What their company does	
		4. Invoicing address	4. Invoice mailing address – Fill in complete address – Attention to whom? – Phone number	
		5. Shipping address	5. Shipping address – Fill in complete address – Attention to whom? – Phone number	

5.2.4 Update the process management plan

How do I do it?

1. **Base the plan for ongoing process management on the Process Management Chart developed in the Design step and tested in the pilot.**

    - Include:

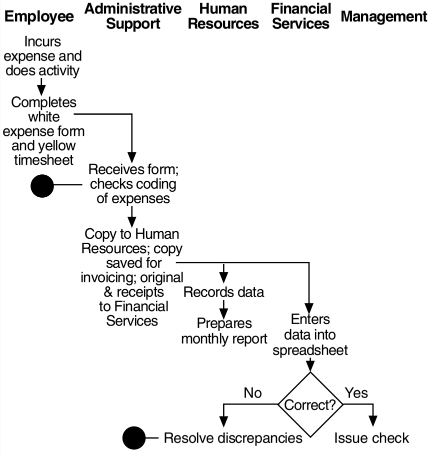
        - A clarification of the process roles and a plan for who will fill those roles.
        - A working version of the Process Management Chart with the major process steps, measures, and response plans included.
        - A working version of the measurement and monitoring systems that you will use to manage the process on an ongoing basis, including what you will measure and how you will track it.
        - A schedule for process reviews.

2. **Use data analysis tools to monitor ongoing performance.**

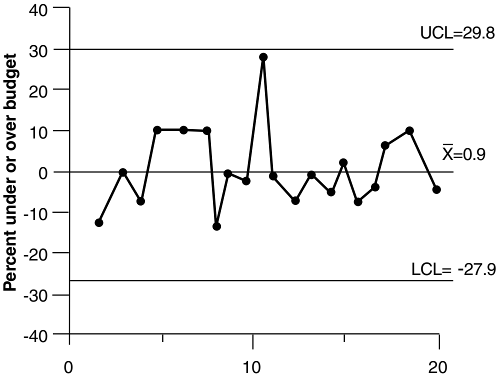
    - To analyze the data from the Process Management Chart on an ongoing basis, have process owners monitor key measures to ensure that the performance level continues to meet requirements, and use appropriate charts (like a Control Chart) to display and analyze this data.

      Note: An in-depth discussion of Control Charts is beyond the scope of this book. For more information, see *The Memory Jogger™ II*.

A Sample Process Management Chart

The plan for doing the work	Checking the work	Response to results
Flowchart	**Key process indicators**	**Corrective actions**
	100% inspection for standards: 1. Received by 5 p.m. Tues. (on-site) or 5 p.m. Wed. (by mail). 2. Operational definitions of expenses used. 3. Complete information provided. 4. Columns added and summary completed.	Correct form or return to employee. Discuss corrections with employee. Provide training if needed.
	Receipts behind form, stapled in upper left corner.	Correct form or return to employee. Discuss corrections with employee. Provide training if needed.
	Human Resources does 100% inspection for proper use of time coding, vacation, leave, and holiday expenses used.	If unclear about budget codes, check with manager.
	Financial Services responsible for: 1. All charges allocated. 2. Proper use of budget codes.	If incorrect: 1. Work with Administrative Support to resolve. 2. Track common areas of problems and report to manager monthly.

A Sample Control Chart to Display Performance Data



- Before using charts to monitor ongoing performance, decide:
  - Who will collect the data.
  - Who will plot the data.
  - Who will interpret the chart.
  - What they should do if a signal of special cause appears.
  - Where you will post the chart.
  - Whether you will create the chart by hand or on computer.
- Decide who will be responsible for the upkeep of the charts and for reacting to any signals. Make sure that everyone involved in using the chart has been trained to collect and plot the data, and understands special cause and common cause variation.

5.2.5 Update the implementation plan FMEA/EMEA

Because implementation and transition plans are complex, you must have a plan to minimize potential problems and take actions to minimize the likelihood of those problems. Analyze the pilot to identify new sources of failure or error, and continue to use the FMEA/EMEA to identify steps where problems are likely to occur and where the consequences of problems are serious.

As you develop contingency plans to minimize the likelihood of problems, consider:

- Developing communication plans to combat misunderstandings.
- Developing or revising key documentation so that critical plan steps are identified and understood.
- Making key process steps error-proof.
- Adding additional or more-skilled resources to vulnerable steps along the critical path.

5.2.6 Carry out the implementation

Use the PDCA Cycle, just as you did in the pilot, to implement the design.

5.2.7 Review the implementation

Complex implementations may require a final review *after* you begin to roll-out the design but *before* you close the project. This review ensures that the organization is prepared to assume responsibility for continued roll-out and ongoing monitoring of the design.

How do I do it?

1. **Review any problems encountered during implementation, analyze the causes, and identify any efforts to remedy the problems.**

2. **Analyze any performance gaps and address efforts to close the gaps.**
3. **Revise the plans for continued roll-out and monitoring.**

5.3 Close the Project

How do I do it?

1. **Transition the responsibilities for the implemented design to management and the process owners/operators, and communicate the results of the design project throughout the organization.**
   - Communicating the project results helps the design team and the organization recognize when the design project is completed and ongoing responsibility for maintaining the performance has shifted to the process owners in various operations.
2. **Once you have transitioned the responsibilities for implementation, complete a formal closure process that:**
   - Captures the lessons learned about the design process.
   - Communicates the project's ending.
   - Recognizes the considerable time and effort that went into the initiative.

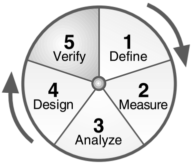
   Tip Some design projects never seem to end. Often this is because the organization is unprepared to assume its responsibilities for ongoing project management, which, with some designs, can take considerable time. Sometimes the team is reluctant to leave the new design in the hands of ongoing operations. Sometimes both the organization and the team are simply unclear about when the team's responsibilities are fulfilled.

It is important to have a clear closure to a project, even if the same design team is to work on the next generation of the design.

5.3.1 Capture the lessons learned about the design process

1. **Capture, compile, and share the lessons learned in the design process so that current and future design projects can leverage and apply them.**
   - Capture learnings:
     - About your results.
     - About the design process:
       - What you learned about the design process that surprised you.
       - What you learned about conducting a design project.
       - What advice you would give to other teams.
       - What helped your team and what hindered it.
       - What worked and what didn't.
     - About the team's functioning:
       - What you learned about working on a team.
       - How well your team worked together.
       - How well you worked with a sponsor and reviewers.
2. **Use a final tollgate review to capture the lessons learned.**
   - Update the Storyboard.
   - Present a progress report at the tollgate meeting using the Tollgate Review Form.

The Verify Tollgate Review Form



Verify:
Implement the design
and close the team

Deliverables:

- ❑ Working prototype with documentation
- ❑ Implementation plans
- ❑ Process management plans being used
- ❑ Completed project documentation
- ❑ Transfer of ownership

- What was learned from the pilot? What changes were made as a result?
- Has ownership been transferred to the process owner and process team?
- What process management plans were created to monitor process performance over time?
- Is all documentation complete for both the process and the project?
- Do you need to address any change issues?
- Do you need to resolve any other open issues?
- Did you uncover any other potential projects during your design work?
- What are your key learnings from the Verify step?

- Discuss the progress report and any issues that arose; ask and answer questions about data and logic.
- Identify the project's strengths and weaknesses.
- Identify the review's strengths and weaknesses.

5.3.2 Communicate the project's ending

Join with the project team and its sponsor(s) in communicating the team's results to the organization. Include:

- What the team accomplished.
- The impact on the organization.
- Which employees could benefit from the lessons learned.
- The best method to communicate the lessons learned.

5.3.3 Recognize the time and effort that went into the initiative

Select an appropriate way to celebrate closure and determine how you will close the team.

> ***Tip*** Recognition is an important part of celebration and should reinforce intrinsic sources of satisfaction and motivation.

Additional Resources

Web-based sources of information

www.isixsigma.com
Solely dedicated to Six Sigma; excellent source of free information on all facets of Six Sigma.

www.pdma.org
Site for the Product Development and Management Organization; has an especially helpful glossary of terms.

www.asmsup.com
Site for the American Supplier Institute; excellent source for Taguchi Methods and Quality Function Deployment.

www.sei.cmu.edu
Site for the Software Engineering Institute (SEI); source of the Capability Maturity Model for software development.

www.aiag.org
Site for the Automotive Industry Action Group; excellent source of information on the automotive Production Part Approval Process (PPAP).

www.triz-journal.com
Site dedicated to providing information about "Theory of Inventive Problem Solving," (TRIZ) developed by Genrich Altshuller; contains articles and case studies.

Text-based sources of information

For more information on:	Refer to:
Brainstorming and Brainwriting	*The Creativity Tools Memory Jogger™* or *The Idea Edge*
Control Charts	*The Memory Jogger™ II*
Creative Confrontation Methods	*The Creativity Tools Memory Jogger™*
Creativity Tools	*The Creativity Tools Memory Jogger™*, *The Idea Edge*, or *Product Design: Fundamentals and Methods* by N.J.M. Roozenburg, J. Eekels, and N.F.M.Roozenburg, John Wiley & Sons
Data Analysis Tools	*The Six Sigma Memory Jogger™ II*
Design of Experiments	*The Six Sigma Memory Jogger™ II* or *The Black Belt Memory Jogger™*

Continued on next page

For more information on:	Refer to:
Design Reviews	*Product Design Review—A Method for Error-Free Product Development*, Takeshi Ichida (editor), Productivity Press
Design Scorecards	*Design for Six Sigma: A Roadmap for Product Development* by Kai Yang and Basem El-Haik, McGraw-Hill
Flowcharts	*The Memory Jogger™ II*
Morphological Box	*The Creativity Tools Memory Jogger™* or *The Idea Edge*
Performance Functions (y = *f* (x))	*The Black Belt Memory Jogger™*
Process Analysis Tools	*The Six Sigma Memory Jogger™ II*
Project Management Tools	*Project Management Memory Jogger™* or *The Six Sigma Memory Jogger™ II*
Project Planning Tools	*Project Management Memory Jogger™* or *The Six Sigma Memory Jogger™ II*
Pugh Matrix	*The Idea Edge*
Rolled Throughput Yield	*The Black Belt Memory Jogger™*
Run Charts	*The Memory Jogger™ II*
Scatter Diagrams	*The Memory Jogger™ II*
Selecting and Sorting Customer Statements	*Voices into Choices: Acting on the Voice of the Customer* by Gary Burchill and Christina Hepner Brodie, Oriel Incorporated
Sigma Values	*The Black Belt Memory Jogger™*
Standardization Tools	*The Six Sigma Memory Jogger™ II*
Storyboards	*The Six Sigma Memory Jogger™ II* or *The Problem Solving Memory Jogger™*
TRIZ	*Design for Six Sigma: A Roadmap for Product Development* by Kai Yang and Basem El-Haik, McGraw-Hill; or GOAL/QPC Research Report, *TRIZ: An Approach to Systematic Innovation*
Uncovering Customer Needs	"Want to Perfect Your Company's Service? Use Behavioral Science" by Richard B. Chase and Sriram Dasu, *Harvard Business Review*, June 2001

Unless noted otherwise, all resources are GOAL/QPC publications.

Storyboard

Note: The information in this section is adapted from *The Six Sigma Memory Jogger™ II.*

What is it?

The Storyboard is a graphical or pictorial record of your design project to help you track data, decisions, and actions.

Why use it?

- To facilitate decision making
- To help maintain forward momentum
- To help prevent rework
- To provide a quick, visual summary of a team's work

Note: You can also use the elements of a Storyboard as presentation materials. Many organizations keep Storyboards permanently on record so that employees can have access to other team's work.

How do I do it?

1. **Maintain records throughout the life of your project.**
   - Agendas and meeting notes provide a permanent record of what issues are discussed at meetings–particularly what "to do" items you generated and what decisions you reached.
   - Records of customer interviews or surveys provide verbal data that will help to shape your effort.

Management, sponsors, or others in the organization might find this data helpful to use for future efforts.

- Data-collection sheets provide the source for your analysis. Keep them at least until the project is completed.
- Plans help you identify the components of a task, track your progress, and communicate your progress to others. Documented plans help you evaluate whether you did what you intended to do; they can also provide the basis for standardized work plans.
- Data charts help you understand your data, enable you to compare the outcome of the design effort with the initial situation, and provide a baseline for monitoring the process and making future improvements.

2. **Create a Storyboard.**

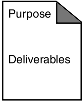
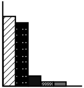
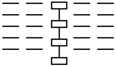
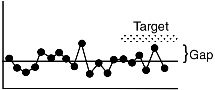
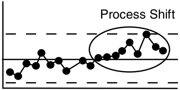
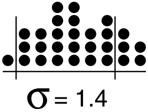
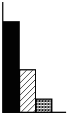
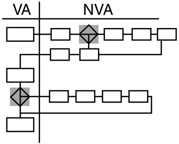
   - Develop a pictorial record of the design steps by using the template on the following pages.

   Tip Keep your text brief, use a lot of graphics, and make sure your graphics effectively communicate your message.

3. **Present your Storyboard to others.**

   Organizations often ask design project participants to introduce others in the organization to new concepts, explain a concept or tool they used, and present examples of their applications of various concepts and tools. This is often done as a formal presentation.

Storyboard Template

Text	Typical Graphics
Discussion of charter	**Charter**  **VOC Data**  **SIPOC Map**  **Other Charts Depicting Gap** 
Interpretation of data and graphics	**Control Chart** showing patterns in variation over time  **Frequency Plot** (Histogram) showing patterns in distribution and **calculations**  **Pareto Chart** showing relative importance of different components of the problem  **Flowchart** depicting current process 

Continued on next page

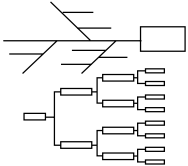
Storyboard Template (cont.)

Text | **Typical Graphics**

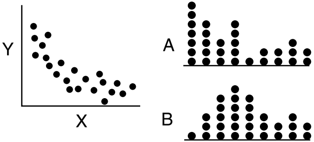
Reasons for selecting causes for verification

Interpretation of verification data

Cause & Effect Diagram (or other tool showing potential causes identified)



Scatter Plot, Stratified Frequency Plots, or Tables showing verification data



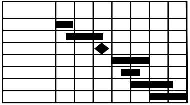
Explanations of criteria

Comments on plans and tests

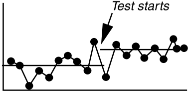
Matrix showing ranked criteria and scoring for each solution option

A	●		○	4
B	●	●	●	1
C	△	○	●	3
D	●	△	●	2

Plans for implementation



Results of pilot tests



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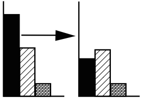
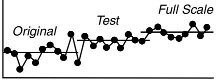
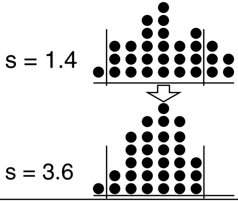
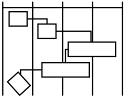
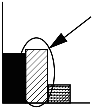
Storyboard Template (cont.)

Text	Typical Graphics
Interpretation of analysis of results and methods	**Before and After Data** Comparing results with data previously collected. Plots drawn to same scale.   
Comments on training plans and ongoing monitoring responsibilities	**Samples of standardization documentation** including revised flowcharts, etc. 
Summary of learnings and suggestions for next steps Plans for celebration and recognition	*Learnings* Charts showing areas that still need improvement 

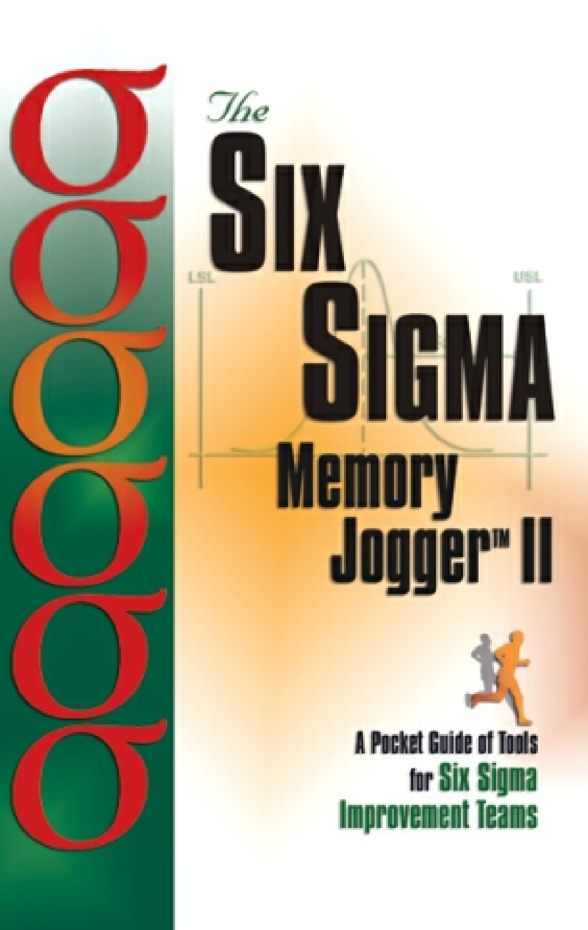
Sigma Conversion Chart

Long-term Yield	Long-term Sigma	Short-term Sigma	Defects per Million
99.99966%	4.5	6.0	3.4
99.9995%	4.4	5.9	5
99.9992%	4.3	5.8	8
99.9990%	4.2	5.7	10
99.9980%	4.1	5.6	20
99.9970%	4.0	5.5	30
99.9960%	3.9	5.4	40
99.9930%	3.8	5.3	70
99.9900%	3.7	5.2	100
99.9850%	3.6	5.1	150
99.9770%	3.5	5.0	230
99.9670%	3.4	4.9	330
99.9520%	3.3	4.8	480
99.9320%	3.2	4.7	680
99.9040%	3.1	4.6	960
99.8650%	3.0	4.5	1,350
99.8140%	2.9	4.4	1,860
99.7450%	2.8	4.3	2,550
99.6540%	2.7	4.2	3,460
99.5340%	2.6	4.1	4,660
99.3790%	2.5	4.0	6,210
99.1810%	2.4	3.9	8,190
98.930%	2.3	3.8	10,700
98.610%	2.2	3.7	13,900
98.220%	2.1	3.6	17,800
97.730%	2.0	3.5	22,700
97.130%	1.9	3.4	28,700
96.410%	1.8	3.3	35,900
95.540%	1.7	3.2	44,600
94.520%	1.6	3.1	54,800
93.320%	1.5	3.0	66,800
91.920%	1.4	2.9	80,800
90.320%	1.3	2.8	96,800
88.50%	1.2	2.7	115,000
86.50%	1.1	2.6	135,000
84.20%	1.0	2.5	158,000
81.60%	0.9	2.4	184,000
78.80%	0.8	2.3	212,000
75.80%	0.7	2.2	242,000
72.60%	0.6	2.1	274,000
69.20%	0.5	2.0	308,000
65.60%	0.4	1.9	344,000
61.80%	0.3	1.8	382,000
58.00%	0.2	1.7	420,000
54.00%	0.1	1.6	460,000
50.00%	0.0	1.5	500,000
46.00%	-0.1	1.4	540,000
42.00%	-0.2	1.3	580,000
38.00%	-0.3	1.2	620,000
34.00%	-0.4	1.1	660,000
31.00%	-0.5	1.0	690,000
27.00%	-0.6	0.9	730,000
24.00%	-0.7	0.8	760,000

Note: The 1.5 sigma shift is included in this chart.

GOAL QPC

Improving the Way Organizations Run



The SIX SIGMA Memory Jogger™ II

A Pocket Guide of Tools for Six Sigma Improvement Teams

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First Edition
GOAL/QPC

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Printed in the United States of America

First Edition 10 9 8 7 6 5 4 3 2 1

ISBN 1-57681-044-5

Acknowledgments

Our thanks and gratitude go to the people and organizations who offered encouragement and suggestions for this book or who gave us permission to use their examples, graphs, and charts.

Special thanks to Patricia Klossner, president of Oriel Inc., who generously and graciously enabled us to access the wealth of experience she and her team have gained in working to develop Six Sigma leaders and team members. Since 1995, when we collaborated to produce *The Team Memory Jogger™*, Pat has been a model partner and a great friend.

Thanks also to Kristi Brown, *Wal-Mart;* and Ruth Fattori, *Conseco Inc.,* who reviewed and critiqued draft copy to ensure that the book met their expectations, and to everyone who helped with the original *Memory Jogger™ II*: Bryce Colburne, *AT&T Technologies;* Robert Brodeur, *Bell Canada;* Karen Tate, *BGP;* Rip Stauffer, *BlueFire Partners;* Weston F. Milliken, *CUE Consulting;* Raymond A. Kach, *Ford Motor Company;* Paula McIntosh, *Georgia State Dept. of Human Resources, Division of Rehabilitation Services;* Donald Botto, *Goodyear Tire & Rubber Company;* Tony Borgen and Paul Hearn, *Hamilton Standard;* Lloyd S. Nelson, *Nashua Corp.;* Jack Waddell, *Novacor Chemicals;* Kirk Kochenberger, *Parkview Episcopal Medical Center;* Marie Sinioris, *Rush-Presbyterian-St. Luke's Medical Center;* Tim Barnes, *Smith-Kline Beecham;* Dennis Crowley, *St. John Fisher College;* Buzz Stapczynski, *Town of Andover, MA;* Kemper Watkins, MSgt., *U.S. Air Force, Air Combat Command;* Capt. T. C. Splitgerber, *U.S. Navy, Naval Dental Center, San Diego, CA.*

Foreword

Published in 1994, the original *Memory Jogger™ II* introduced many of the quality tools commonly used for process improvement, planning, and problem solving, but it lacked specific information on how and when these tools should be used in support of Six Sigma.

In the late 1990s, many leading Six Sigma organizations began asking us to create customized versions of *The Memory Jogger™ II*. In additon to the quality tools, these books also contained company-specific Six Sigma material. In time, we concluded that a widespread need existed that would be met if we created *The Six Sigma Memory Jogger™ II*.

To that end, we enlisted the help of Oriel Inc. of Madison, Wisconsin, to ensure that this book's content is appropriate for Six Sigma team members. Oriel has extensive experience in training and coaching Six Sigma teams and project leaders.

We believe that the insights contained in this book, which we have gathered from many sources, combine to create a valuable resource for helping Six Sigma teams to learn and apply these powerful quality tools. We trust you will agree.

Bob Page
GOAL/QPC

Table of Contents

Six Sigma Overview

What is Six Sigma?

Sigma is a statistical concept that represents the amount of variation present in a process relative to customer requirements or specifications. When a process operates at the six sigma level, the variation is so small that the resulting products and services are 99.9997% defect free.

"Six Sigma" is commonly denoted in several different ways. You might see it written as "6σ," "6 Sigma," or "6s."

In addition to being a statistical measure of variation, the term *Six Sigma* also refers to a business philosophy of focusing on continuous improvement by understanding customers' needs, analyzing business processes, and instituting proper measurement methods. Furthermore, it is a methodology that an organization uses to ensure that it is improving its key processes.

While Six Sigma corresponds to being 99.9997% defect free, not all business processes need to attain this high a goal. Companies can also use the Six Sigma methodology to identify which of their key business processes would benefit most from improvement and then focus their improvement efforts there.

In this book, we often use the more generic terms *sigma* or *process sigma* to refer to the current capability of a process (i.e., how well the process is performing relative to customer specifications).

Process Capability

Amount of Variation	Effect	Sigma Value
Too much	Hard to produce output within customer requirements or specifications	Low (0–2)
Moderate	Most output meets customer requirements	Middle (2–4.5)
Very little	Virtually all output meets customer requirements (less than four parts per million not meeting specifications)	High (4.5–6)

To increase your organization's process-sigma level, you must decrease the amount of variation that occurs. Having less variation gives you the following benefits:

- Greater predictability in the process.
- Less waste and rework, which lowers costs.
- Products and services that perform better and last longer.
- Happier customers who value you as a supplier.

The simple example below illustrates the concept of Six Sigma. Note that the amount of data in this example is limited, but it serves to describe the concept adequately.

Two companies deliver pizza to your house. You want to determine which one can better meet your needs. You always want your pizza delivered at 6 p.m. but are willing to tolerate a delivery anytime between 5:45 p.m. and 6:15 p.m. In this example, the target is 6 p.m. and the customer specifications are 5:45 p.m. on the low side and 6:15 p.m. on the high side.

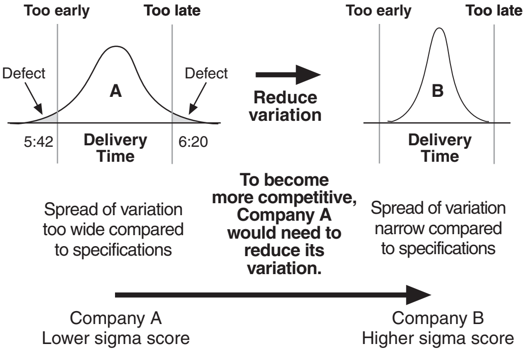
You decide to order two pizzas at the same time every night for ten days—one pizza from Company A, and one from Company B. You track the delivery times for ten days and collect the following data:

Comparison of Delivery Times

Company A		Company B	
Day	Delivery Time	Day	Delivery Time
1	5:58	1	5:51
2	6:20	2	6:04
3	5:49	3	5:59
4	6:05	4	6:00
5	6:10	5	6:10
6	5:42	6	5:56
7	6:01	7	6:02
8	5:53	8	6:11
9	6:12	9	5:59
10	6:05	10	6:09

As the chart above shows, Company A had two occurrences—on Day 2 and Day 6—of pizza arrival times that were outside of your tolerance window of between 5:45 and 6:15. In Six Sigma terminology, these two occurrences are called *defects*. This performance can also be described visually with the following graphs:

Defects and Variation



As mentioned above, a process variation of no greater than Six Sigma is equivalent to being 99.9997% defect free. Although a 99.9% defect-free level of quality (which is equivalent to a sigma level greater than four) sounds adequate, in a world operating at this sigma level, the following situations would occur:

- At least 20,000 wrong drug prescriptions dispensed per year.
- Unsafe drinking water for almost one hour a month.
- No telephone service or television transmission for nearly ten minutes each week.
- Ninety-six crashes per 100,000 airline flights.

Experts believe that the quality levels for most businesses today fall within the three- to four-sigma range.

Six Sigma terminology

Organizations that adopt a Six Sigma philosophy and methodology employ a commonly used and understood vocabulary. These terms are used frequently throughout this book, and you will use them often as you work on your organization's sigma improvement teams. Below is a sampling of these terms.

Critical To Quality (CTQ) characteristic: A key feature by which customers evaluate the quality of your product or service and that can be used as measures for your project. A useful CTQ characteristic has the following features:

- It is critical to the customer's perception of quality.
- It can be measured.
- A specification can be set to tell whether the CTQ characteristic has been achieved.

unit: An item that you produce or process.

defect: Any unit or event that does not meet customer requirements. A defect must be measurable.

defective: A unit with one or more defects.

defect opportunity: A measurable chance for a defect to occur.

sigma: An expression of process yield based on the number of defects per million opportunities, or DPMO.

Where, why, and how did Six Sigma begin?

The Six Sigma philosophy and methodology started at Motorola Corporation in the mid-1980s, when the company discovered that products with a high first-pass yield (i.e., those that made it through the production process defect-free) rarely failed in actual use. Motorola began focusing on creating strategies to reduce defects in its products and in 1988 was among the first group of organizations to win the Malcolm Baldrige National Quality Award. Today, based on its pioneering work, Motorola holds the trademark for the Six Sigma® methodology.

During the mid-1980s, Motorola joined forces with several other companies, including ABB (Asea Brown Boveri), AlliedSignal, Kodak, IBM, and Texas Instruments, to found the Six Sigma Research Institute. This effort began the expansion and commercialization of the process of achieving Six Sigma capability.

The Six Sigma concept and methods have gained popularity in part due to publicity about former General Electric CEO Jack Welch's commitment to achieving Six Sigma capability.

Why should I use Six Sigma?

The benefits of following the Six Sigma concept and using the accompanying methods are many. They include the following:

- Having a measurable way to track performance improvements.
- Focusing your attention on process management at all organizational levels.
- Improving your customer relationships by addressing defects.
- Improving the efficiency and effectiveness of your processes by aligning them with your customers' needs.

Conducting measurable tracking keeps you informed about what changes are working and which ones are not. It can also speed up significant improvement. Having a process focus lets you define defects and calculate sigma levels. Aligning a process with your customers' needs can result in greater customer loyalty and retention. Also, by being in touch with your customers and their needs, you can more easily develop new ideas for improvements and enhancements to your products and services.

How does Six Sigma differ from Continuous Quality Improvement (CQI)?

Although some Six Sigma concepts and tools are similar to those used for CQI, Six Sigma emphasizes the following points:

- An increased focus on quality as defined by your customers. The sigma score directly addresses this issue.
- More rigorous statistical methods.
- Prioritization of your improvement projects and alignment of your resources to support your organization's key strategic initiatives.

If you are familiar with CQI, you are probably already familiar with some of the tools described in this book. But you will also find some new tools that you can add to your Six Sigma tool belt.

If you are not already familiar with CQI, then you will learn many new tools that will help you improve the effectiveness of your organization's processes and their ability to meet your customers' needs.

What is needed for a successful Six Sigma program?

Your process-sigma work will be successful only if your organization has an environment that supports its continued and consistent use. To accomplish this, your organization should do the following:

- Have management lead your improvement efforts.
- Actively support a focus on delighting your customers.

- Provide the sigma improvement team with access to experts who can offer ongoing guidance and coaching.
- Encourage open discussion about defects. People should not be afraid to point out that something is wrong. The airline industry, for instance, studies crashes and "near-misses" to improve safety.
- Value and use the data you gather.
- Help employees work effectively by providing a team-based, cooperative environment.

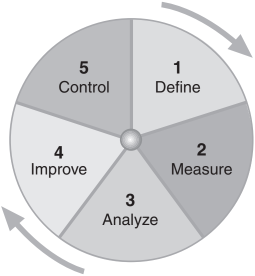
What are the Six Sigma methodologies?

There are two basic methodologies introduced in Six Sigma organizations. They are known by their acronyms: DMAIC and DMADV.

The DMAIC method involves five steps: **D**efine, **M**easure, **A**nalyze, **I**mprove, and **C**ontrol. This method is used to improve the current capabilities of an existing process. This is by far the most commonly used methodology of sigma improvement teams and is described in detail in the next section of this book.

In the DMAIC method, the CTQs are defined first. The improvement team then studies each one intensively to understand the key drivers that influence successful process performance. Improvements in the key drivers can then be made, and the process can attain the required Six Sigma level and thereby meet the CTQs.

The Five Steps of the DMAIC Method



The five steps of the DMAIC method are outlined below.

1. Define the project.

- Define the project's purpose and scope.
- Collect background information on the process and your customers' needs and requirements.

2. Measure the current situation.

- Gather information on the current situation to provide a clearer focus for your improvement effort.

3. Analyze to identify causes.

- Identify the root causes of defects.
- Confirm them with data.

4. Improve.

- Develop, try out, and implement solutions that address the root causes.
- Use data to evaluate results for the solutions and the plans used to carry them out.

5. Control.

- Maintain the gains that you have achieved by standardizing your work methods or processes.
- Anticipate future improvements and make plans to preserve the lessons learned from this improvement effort.

The DMAIC method is very robust. Many organizations have used it successfully to produce dramatic improvements. Using the DMAIC method also results in the following benefits:

- It provides a framework.
- It provides a common language.
- It provides a checklist to prevent skipping critical steps in the process.
- It enables you to improve the way in which you improve.

Note: Some organizations use the RDMAIC method, in which a Recognize step is added to the beginning of the improvement process. This step involves using techniques to identify the most urgent projects to work on and/or the ones that will result in the greatest benefit to the organization and its customers.

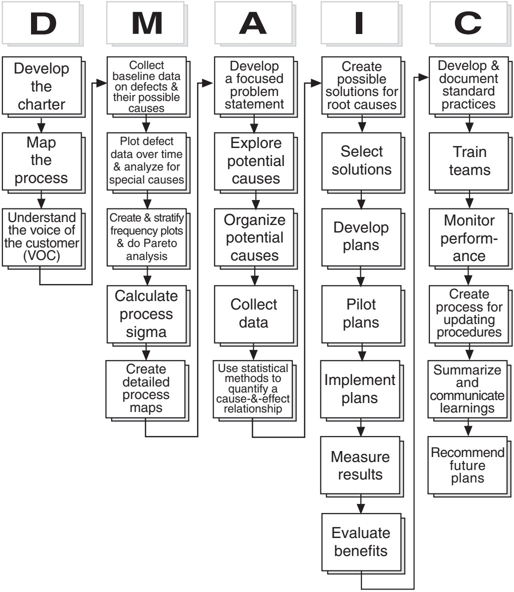
The DMADV method is used when you need to create a process, product, or service to meet customer requirements or when you need a complete redesign because the process, product, or service is consistently incapable of meeting customer requirements. This method is much less frequently used than the DMAIC method. DMADV teams are usually convened and staffed by senior managers. While many of this method's tools and processes are the same as for DMAIC, others are typically performed only by Six Sigma Experts. These tools are beyond the scope of this book.

Like the DMAIC method, the DMADV method involves five steps: **D**efine, **M**easure, **A**nalyze, **D**esign, and **V**erify. In this method, the improvement team defines the CTQs first. The team then creates a product, service, or process that optimizes performance so it satisfies the critical CTQs.

DMAIC

As a Six Sigma team member, you will most likely work on improvement teams using the DMAIC method. To use this method successfully, you must first be familiar with the goals and outputs of each step, as well as the correct approach to take during each step and the tools necessary to complete your work.

The DMAIC Process Flow



The goals, outputs, approach, and tools for each step of the DMAIC method are outlined on the next several pages.

The Define Step

Goals and outputs

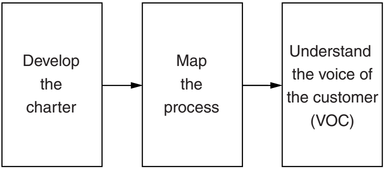
The goal of the Define step is to define the project's purpose and scope and obtain background information about the process and its customers.

The outputs of the Define step consist of the following:

- A clear statement of the intended improvement and how you will measure it.
- A high-level map of the process.
- A translation of the voice of the customer, or VOC (see page 258 for details), into key quality characteristics.

Approach

The "Define Step" Process Flow



To fully define the scope and purpose of your project, you must first understand the boundaries of the process you are trying to improve and the requirements of its customers. You include this information, along with expected resource needs and a projected timeline, in your team charter.

In practice, there is usually some give and take between these activities as you work to define a project that is both important and doable.

The applicable tools for the Define step include the following:

Tool	Description	Page
Affinity Diagram	Enables your team to organize and summarize language-based data.	38
Charter	Documents what the project is supposed to achieve and what resources are available to your team. A written charter is an important communication and reference tool.	59
Communication Plan	Regular communication with stakeholders (i.e., people who will be affected by the project or can influence it but are not directly involved with doing the project work) can help your team understand its work, identify better solutions to problems, create more buy-in, understand when and how to best involve others, and avoid pitfalls.	70
Control Charts	Focus attention on detecting and monitoring process variation over time.	75
CTQ Tree	Critical To Quality (CTQ) characteristics are features by which customers evaluate the quality of your product or service. The CTQ Tree enables your team to describe your customers' needs and the corresponding measurable characteristics. If a product or service does not meet a CTQ, it is considered to be defective.	91
Data Collection	Data from customers helps your team understand what's important about your project and set priorities if you need to narrow the project's scope. Often the necessary customer data is provided to a team when it is formed.	95

Continued on the next page

Tool	Description	Page
Kano Model	Helps your team understand your customers' requirements, which are sorted into three categories: Must Be, More Is Better, and Delighters.	158
Pareto Chart	Helps your team focus its efforts on the problems that are causing the most trouble. This helps you identify the areas where your efforts will have the biggest payback.	178
Run Chart	Enables your team to study baseline process performance to identify trends or patterns over time.	221
SIPOC	A SIPOC (Suppliers, Inputs, Process, Outputs, and Customers) analysis helps your team understand the key elements of your process and define the boundaries and scope for your project.	235
Tollgate Review	A formal review process that helps keep the project on track and helps promote successful results.	247
$y = f(x)$ Formula	Allows your team to structure the relationship among the Y's (the CTQs), the y's (the process outputs directly affecting the Y's), and the x's (the causal factors directly affecting the y's).	263

The Measure Step

Goals and outputs

The goal of the Measure step is to focus your improvement effort by gathering information about the current situation.

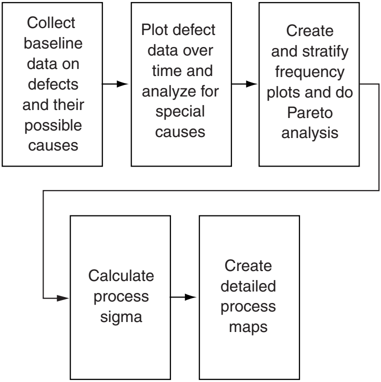
The outputs of the Measure step include the following:

- Data that pinpoints the problem's location or rate of occurrence.

- Baseline data on how well the process meets customer needs (to determine the current process sigma).
- An understanding of how the current process operates.
- A more focused problem statement.

Approach

The "Measure Step" Process Flow



During the Measure step, you investigate the problem you are studying in detail—what specifically is happening, when it is happening, and where it is happening. You also collect data to create a performance baseline to which you can compare the process performance after you work on the Improve step.

The applicable tools for the Measure step include the following:

Tool	Description	Page
Control Charts	Help you look for patterns over time in process variation, quantify the current capability of your process, and identify when special events interrupt normal operations.	75
Data Collection	Helps you systematically collect baseline data.	95
Data Points/ Data Types	The type of data you have will determine which tool(s) to use.	101
Flowchart	Pinpoints steps in the process that don't add value and helps you identify problems in the process that contribute to waste and defects.	116
Histogram	Reveals how often a problem occurs in different settings. A stratified Histogram helps you identify process characteristics that might provide clues about the potential causes of problems.	129
Measurement Systems Analysis (MSA)	Helps you understand measurement variation.	168
Operational Definitions	Precise descriptions that describe how to get a value for each characteristic you are trying to measure.	176
Pareto Chart	Displays the relative importance of problems. As in the Define step, it helps you focus your attention and develop a detailed problem statement.	178
Process Sigma	Calculations that describe the current process capability. Calculating a baseline process-sigma level provides a gauge for you to evaluate your progress.	204
Run Chart	Plots data from Check Sheets and other sources and helps you look for patterns over time in process variation.	221

Continued on the next page

Tool	Description	Page
Taguchi Loss Function	Defines the loss associated with variation around a customer-specification target.	244
Tollgate Review	A formal review process that helps keep the project on track and helps promote successful results.	247

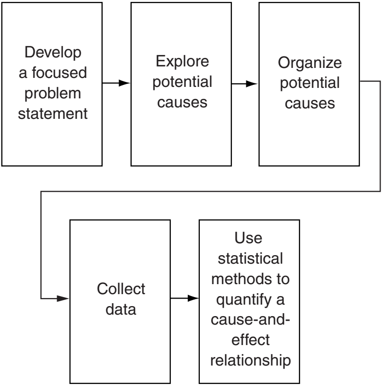
The Analyze Step

Goals and outputs

The goal of the Analyze step is to identify root causes and confirm them with data. The output of this step is a theory that you have tested and confirmed.

Approach

The “Analyze Step” Process Flow



The Analyze step pinpoints the specific cause(s) of the focused problem statement you will develop as a result of the Measure step. You can then address the root cause(s) through solutions you implement in the Improve step.

The applicable tools for the Analyze step include the following:

Tool	Description	Page
Brainstorming	Enables your team to creatively and efficiently generate a large number of ideas about causes of error.	45
Cause-and-Effect Diagram	Enables your team to identify, explore, and graphically display, in increasing detail, all the possible causes related to a problem. The deeper you are able to push for causes, the more likely your solutions will be long-lasting ones.	49
Design of Experiments (DOE)	Provides a method for testing multiple potential causes of error at the same time, enabling your team to reach conclusions about the primary causes.	105
Focused Problem Statement	Describes specifically what occurs, when or under what circumstances it occurs, and/or who is involved. The goal is to narrow the problem definition so you can use your time and resources most effectively to find a solution.	124
Histogram	Stratified Histograms help you identify process characteristics that might confirm patterns. Like Scatter Diagrams, they help you understand relationships that can confirm an underlying cause of a problem.	129
Hypothesis Testing	Using statistical analysis on a cause-and-effect relationship.	142

Continued on the next page

Tool	Description	Page
Interrelationship Digraph (ID)	Studying cause-and-effect patterns to identify the key drivers and outcomes of critical issues.	147
Scatter Diagram	Used to show the relationship between two variables. It can help your team verify causal relationships.	228
Tollgate Review	A formal review process that helps keep the project on track and helps promote successful results.	247
Tree Diagram	Breaks down the broad categories of causes into increasing levels of detail. Your team can use it to depict the links between root causes and their effects on a problem.	249

The Improve Step

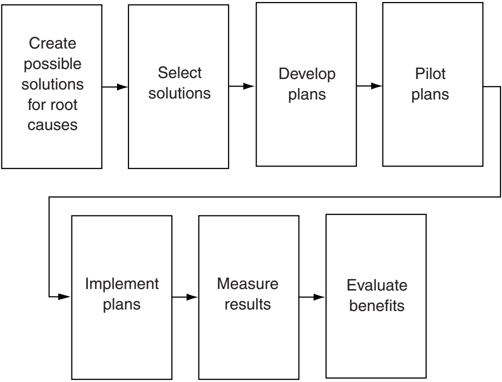
Goals and outputs

The goal of the Improve step is to develop, try out, and implement solutions that address root causes and to use data to evaluate the solutions as well as the plans you use to carry them out.

The outputs of the Improve step include the following:

- Planned, tested actions that eliminate or reduce the impact of the identified root cause(s) of a problem.
- "Before" and "after" data analysis that shows how much of the initial gap was closed.
- A comparison of the plan to the actual implementation.

The "Improve Step" Process Flow



The Improve step involves not only coming up with solutions but also using the PDCA (Plan-Do-Check-Act) Cycle to evaluate and improve the solutions you want to implement. Preparing people for change is another critical component of this step.

The applicable tools for the Improve step include the following:

Tool	Description	Page
Activity Network Diagram/ Gantt Chart	Helps you keep track of your implementation plans.	27
Brainstorming	Enables your team to creatively and efficiently generate a large number of possible solutions.	45

Continued on the next page

Tool	Description	Page
Commitment Scale	Helps your team understand how much work must be done to achieve desired levels of commitment.	67
Control Charts	In the Improve step, these charts are used to show past and present performance of an indicator. Since Control Charts (and Run Charts) show plots of results as time passes, they are excellent tools for determining whether a solution has any real, lasting effect on your process.	75
Failure Mode and Effects Analysis (FMEA)	Used to anticipate potential problems, allowing your team to take counter-measures to reduce or eliminate risks.	111
Histograms	Comparing "before" and "after" Histograms shows how much progress has been made.	129
Involvement Matrix	Helps your team think about who should be involved in the different steps needed to make change a reality, as well as the level of involvement that is appropriate for each of them.	156
Pareto Chart	As with Histograms, comparing "before" and "after" Pareto Charts is a way to objectively see how much progress has been made.	178
PDCA Cycle/ Pilot	The PDCA (Plan-Do-Check-Act) Cycle is the basic methodology behind a pilot. A pilot is a test of the whole system on a small scale to evaluate a solution and to make its full-scale implementation more effective.	199
Prioritization Matrix	Helps you objectively evaluate alternative solutions to a problem. The key is reaching consensus on the relative importance of different criteria first and then weighting the alternatives against those criteria.	189

Continued on the next page

Tool	Description	Page
Process Sigma	The true gauge of the effectiveness of any solution will show up in the new process-sigma level.	204
Run Chart	Like a Control Chart, a Run Chart shows whether a solution has any real, lasting effect on your process.	221
Tollgate Review	A formal review process that helps keep the project on track and helps promote successful results.	247

The Control Step

Goals and outputs

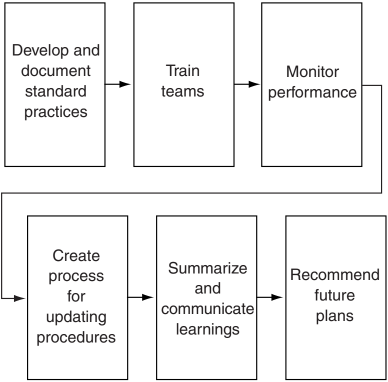
The goal of the Control step is to maintain the gains you have made by standardizing your work methods or processes, anticipating future improvements, and preserving the lessons you learn from this effort.

The outputs of the Control step include the following:

- Documentation of the new method.
- Training of fellow employees in the new method.
- A system for monitoring the consistent use of the new method and for checking the results.
- Completed documentation and communication of the results, learnings, and recommendations.

Approach

The “Control Step” Process Flow



Many tools can help you monitor and control processes. Simply thinking in terms of PDCA (Plan-Do-Check-Act)—or, in this case, SDCA (Standardize-Do-Check-Act)—creates a mentality of constantly checking the effectiveness of your current methods. Training ensures consistency of application, as do “conspicuous standards” that make it easy for employees to do the job correctly.

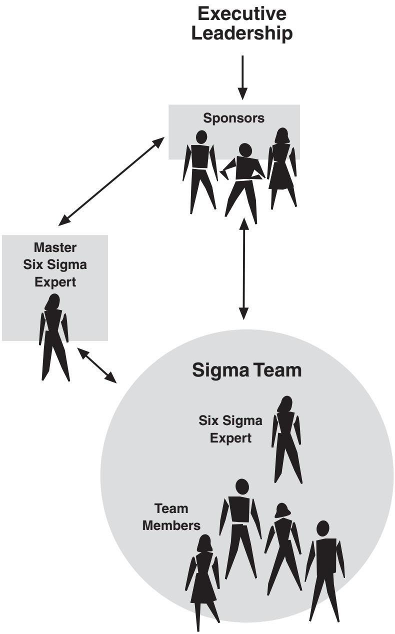
The applicable tools for the Control step include the following:

Tool	Description	Page
Communication Plan	Helps you communicate effectively with the rest of the organization about the project.	70
Control Charts	Monitor progress over time after your project is completed. They can help your team continually quantify the capability of your process and identify when special events interrupt normal operations. It is typically part of the Process Management Chart.	75
PDCA Cycle	Serves as a reminder to think of improvement as being continual: Where can you go next to make the process even better?	199
Process Management Chart	Documents your PDCA—the plan for doing the work, how to check the results, and how to act if something undesirable or unexpected shows up. It also serves as a self-audit tool for checking how well and how consistently the new standards are applied.	199
Run Chart	Monitors progress over time after a project is completed. It is typically part of the Process Management Chart.	221
Six Sigma Storyboard	A pictorial record of your project. Typical documents include a succinct final report and a completed Storyboard that captures the project in graphical form.	239
Tollgate Review	A formal review process that helps keep the project on track and helps promote successful results.	247

DMAIC team structure

In most Six Sigma efforts, companies divide the responsibilities for accomplishing the improvement into four major roles: the sponsor; the team coach, typically called the Master Six Sigma Expert; the team leader, typically called the Six Sigma Expert; and the team member.

The DMAIC Team Structure



Early on in a Six Sigma project, it's important to clarify your team's relationship with your sponsor(s)—the supervisors, managers, or executives who have the power to allocate resources to the project, provide guidance regarding priorities, and ensure the project fits into your organization's business needs. Ongoing support and review by management are critical for your project's success, so part of the project plan should include activities such as weekly communication between the team leader and sponsors, as well as periodic reviews with the entire team.

You will likely also need technical support from a coach—an expert in Six Sigma improvement who has applied the many tools and concepts in practice. Such a person is often called a Master Six Sigma Expert by companies with a Six Sigma program. An organization typically has a few Master Six Sigma Experts who are called on by all its improvement teams.

The Six Sigma Expert leads the improvement team, managing all aspects of the project to meet the goals of the charter. The Six Sigma Expert typically has a strong knowledge of the tools and concepts, as well as some experience in applying them. The Six Sigma Expert might lead one or more teams at any given time, and in many organizations this is a full-time role.

Some organizations assign an additional team leader role, which is separate from the Six Sigma Expert role. In these cases, the Six Sigma Expert focuses on specific and more technical Six Sigma concepts, while the other team leader handles the responsibilities of team meetings, managing the project plan, and other less technical issues.

The team members carry out the work of the project. They learn many Six Sigma tools and concepts and apply these throughout the duration of the project. This book is designed to help you, the team member, make a successful contribution to your Six Sigma improvement team.

Activity Network Diagram (AND)

Scheduling sequential & simultaneous tasks

Why use it?

To allow a team to find both the most efficient path and realistic schedule for the completion of any project by graphically showing total completion time, the necessary sequence of tasks, those tasks that can be done simultaneously, and the critical tasks to monitor.

What does it do?

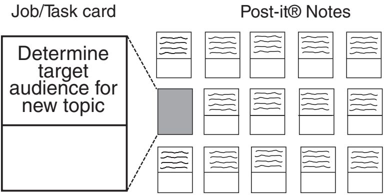
- All team members have a chance to give a realistic picture of what their piece of the plan requires, based on real experience
- Everyone sees why he or she is critical to the overall success of the project
- Unrealistic implementation timetables are discovered and adjusted in the planning stage
- The entire team can think creatively about how to shorten tasks that are bottlenecks
- The entire team can focus its attention and scarce resources on the truly critical tasks

How do I do it?

1. **Assemble the right team of people with firsthand knowledge of the subtasks**

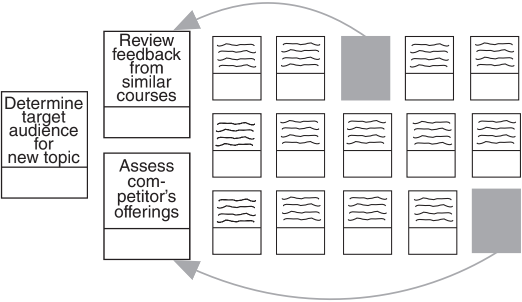
2. **Brainstorm or document all the tasks needed to complete a project. Record on Post-it® Notes**

3. **Find the first task that must be done, and place the card on the extreme left of a large work surface**



4. **Ask: "Are there any tasks that can be done simultaneously with task #1?"**
   - If there are simultaneous tasks, place the task card above or below task #1. If not, go to the next step.

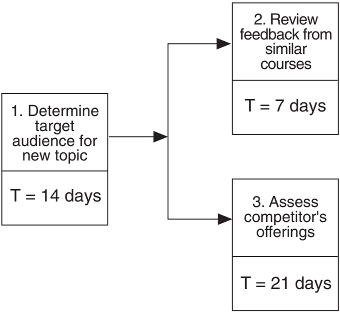
5. **Ask, "What is the next task that must be done? Can others be done simultaneously?"**
   - Repeat this questioning process until all the recorded tasks are placed in sequence and in parallel.



Tip At each step always ask, "Have we forgotten any other needed tasks that could be done simultaneously?"

6. **Number each task, draw the connecting arrows, and agree on a realistic time for the completion of each task**

- Record the completion time on the bottom half of each card.



Tip Be sure to agree on the standard time unit for each task, e.g., days, weeks. Elapsed time is easier than "dedicated" time, e.g., 8 hours of dedicated time versus 8 hours over a two-week period (elapsed time).

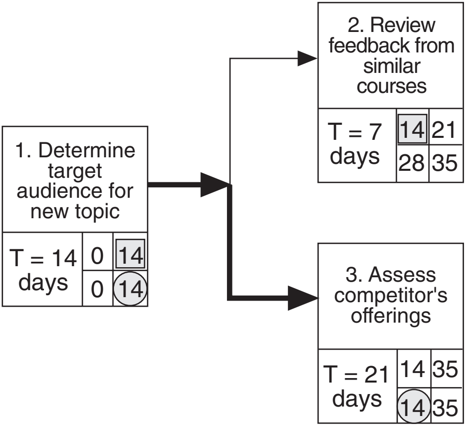
7. **Determine the project's critical path**

- Any delay to a task on the *critical path* will be added to the project's completion time, unless another task is accelerated or eliminated. Likewise, the project's completion time can be reduced by accelerating any task on the critical path.
- There are two options for calculating the total critical path and the tasks included within it.

Longest cumulative path. Identify total project completion time. Add up each path of connected activities. The longest cumulative path is the quickest possible implementation time. This is the project's *critical path*.

Calculated slack. Calculate the "slack" in the starting and completion times of each task. This identifies which tasks must be completed exactly as scheduled (on the *critical path*) and those that have some latitude.

Finding the critical path by calculating the slack



Earliest Start (ES)	Earliest Finish (EF)
Latest Start (LS)	Latest Finish (LF)

ES = The *largest* EF of any *previous* connected task

EF = ES + the time to complete that task

LS = LF - the time to complete that task

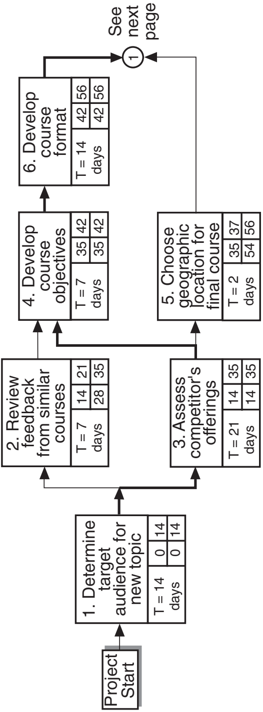
LF = The *smallest* LS of any connected *following* task

When ES = LS AND EF = LF, that task is on the critical path, and therefore there is no schedule flexibility in this task.

Tip Determining the longest cumulative path is simpler than calculating the slack, but can quickly become confusing in larger ANDs.

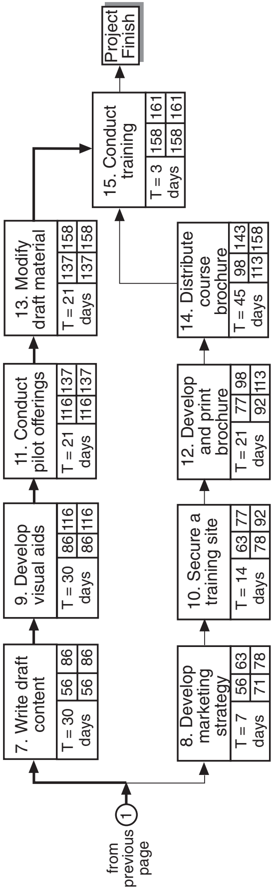
The calculated slack option determines the total project and slack times; and therefore the total project time and critical path are identified "automatically."

Developing a New Course



Project duration: 161 days

Developing a New Course

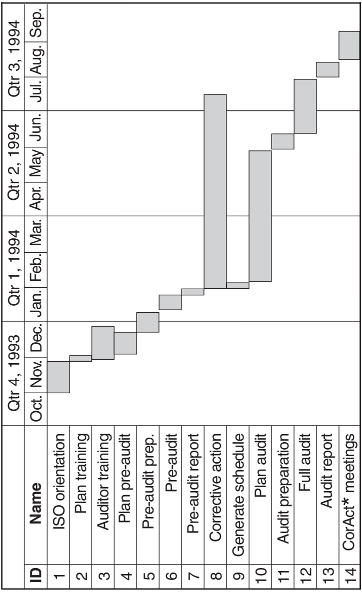


Variations

The constructed example shown in this section is in the Activity on Node (AON) format. For more information on other formats such as Activity on Arrow (AOA) and Precedence Diagram (PDM), see *The Memory Jogger Plus+®*.

Another widely used, schedule-monitoring method is the Gantt chart. It is a simple tool that uses horizontal bars to show which tasks can be done simultaneously over the life of the project.

ISO 9000 Audit Schedule



*CorAct = Corrective action

Key Dates

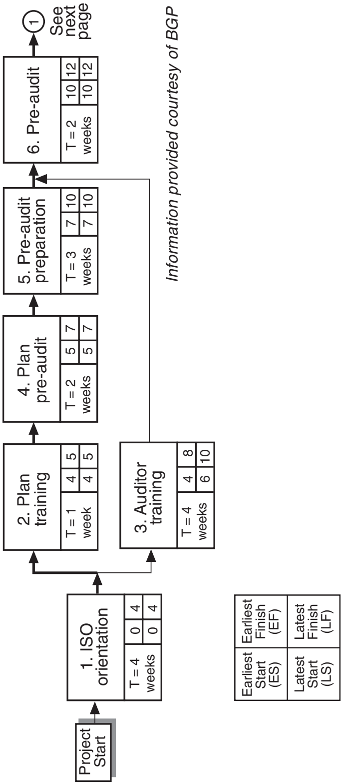
1/3 Release documentation request for pre-audit
1/21 All documentation for pre-audit collected
1/28 Hold pre-audit orientation meeting
2/25 Release full audit schedule
6/13 Commence full audit
7/29 Finish full audit
8/12 Hold full audit orientation meeting

Information provided courtesy of BGP

Activity Network

Phase I

ISO 9000 Certification Audit Schedule

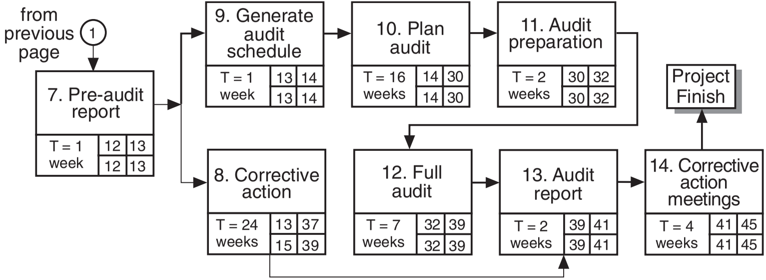


Information provided courtesy of BGP

Activity Network

Phase I

ISO 9000 Certification Audit Schedule (cont.)



Information provided courtesy of BGP

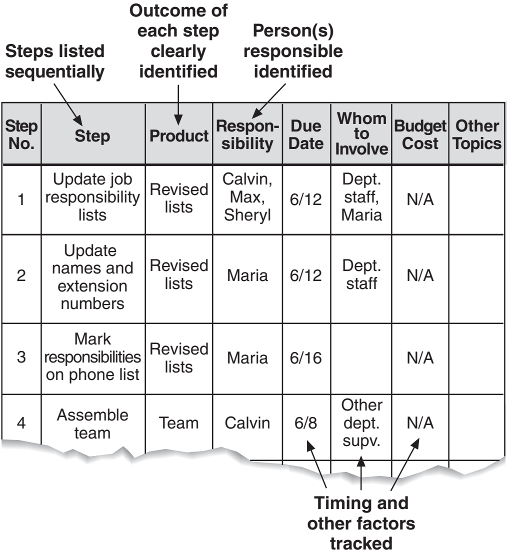
Note: The AND shows that the certification process will take 45 weeks. The bold arrow, indicating the critical path, clearly shows those tasks that must be completed as scheduled. The tasks off the critical path will also require careful monitoring since there is only two weeks of slack time in the schedule.

Planning Grid

A planning grid helps you identify the resources for, and outcomes of, each step in a project. The following features make it easy to use:

- Its table form quickly summarizes the tasks needed to complete a project.
- You can easily customize it to track information specific to your project.
- It is easy to create with pen and paper.

A Sample Planning Grid



Step No.	Step	Product	Respon-sibility	Due Date	Whom to Involve	Budget Cost	Other Topics
1	Update job responsibility lists	Revised lists	Calvin, Max, Sheryl	6/12	Dept. staff, Maria	N/A	
2	Update names and extension numbers	Revised lists	Maria	6/12	Dept. staff	N/A	
3	Mark responsibilities on phone list	Revised lists	Maria	6/16		N/A	
4	Assemble team	Team	Calvin	6/8	Other dept. supv.	N/A	

The steps for completing a planning grid are as follows:

1. Specify the final outcome of the project.
2. Identify the final step and what it produces.
3. Identify the starting point and what it produces.
4. Brainstorm a list of steps that occur between the starting point and the final step.
5. Clean up the list by eliminating duplication, combining related ideas, rewriting unclear statements, and so forth.
6. Label the columns of a grid as shown in the example at left.
7. Write your final list of steps in sequence down the side of the grid.
8. Fill in the Product column for each step.
9. Enter a tentative due date or time for each step.
10. Revise steps if necessary.
11. Complete the remaining columns.

Tip The categories across the top of the grid can vary, depending on the needs of your project.

Affinity Diagram

Gathering &
grouping ideas

Why use it?

To allow a team to creatively generate a large number of ideas/issues and then organize and summarize natural groupings among them to understand the essence of a problem and breakthrough solutions.

What does it do?

- Encourages creativity by everyone on the team at all phases of the process
- Breaks down longstanding communication barriers
- Encourages non-traditional connections among ideas/issues
- Allows breakthroughs to emerge naturally, even on long-standing issues
- Encourages "ownership" of results that emerge because the team creates both the detailed input and general results
- Overcomes "team paralysis," which is brought on by an overwhelming array of options and lack of consensus

How do I do it?

1. Phrase the issue under discussion in a full sentence

What are the issues involved in planning
fun family vacations?

Tip From the start, reach consensus on the choice of words you will use. Neutral statements work well, but positive, negative, and solution-oriented questions also work.

2. **Brainstorm at least 20 ideas or issues**

   a) Follow guidelines for brainstorming.

   b) Record each idea on a Post-it® Note in bold, large print to make it visible 4–6 feet away. Use at minimum, a noun and a verb. Avoid using single words. Four to seven words work well.

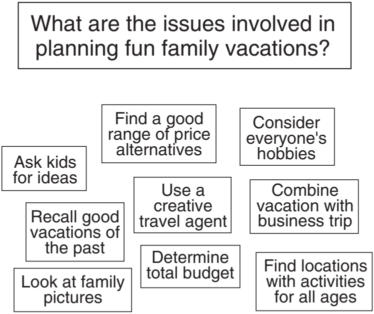


Illustration Note: There are 10 to 40 more ideas in a typical Affinity Diagram

Tip A "typical" Affinity has 40–60 items; it is not unusual to have 100–200 ideas.

3. **Without talking: sort ideas simultaneously into 5–10 related groupings**

   a) Move Post-it® Notes where they fit best for you; don't ask, simply move any notes that you think belong in another grouping.

b) Sorting will slow down or stop when each person feels sufficiently comfortable with the groupings.

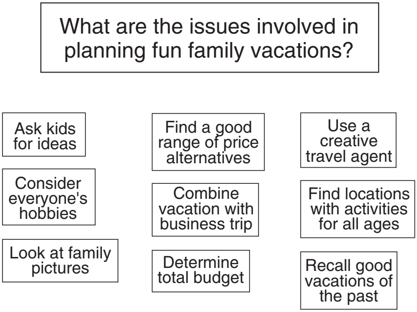


Illustration Note: There are 5 to 10 more groupings of ideas in a typical Affinity Diagram

Tip Sort in silence to focus on the meaning behind and connections among all ideas, instead of emotions and "history" that often arise in discussions.

Tip As an idea is moved back and forth, try to see the logical connection that the other person is making. If this movement continues beyond a reasonable point, agree to create a duplicate Post-it®.

Tip It is okay for some notes to stand alone. These "loners" can be as important as others that fit into groupings naturally.

4. For each grouping, create summary or header cards using consensus

a) Gain a quick team consensus on a word or phrase that captures the central idea/theme of each grouping; record it on a Post-it® Note and place it at the top of each grouping. These are *draft* header cards.

b) For each grouping, agree on a concise sentence that combines the grouping's central idea and what all of the specific Post-it® Notes add to that idea; record it and replace the draft version. This is a final header card.

c) Divide large groupings into subgroups as needed and create appropriate subheaders.

d) Draw the final Affinity Diagram connecting all finalized header cards with their groupings.

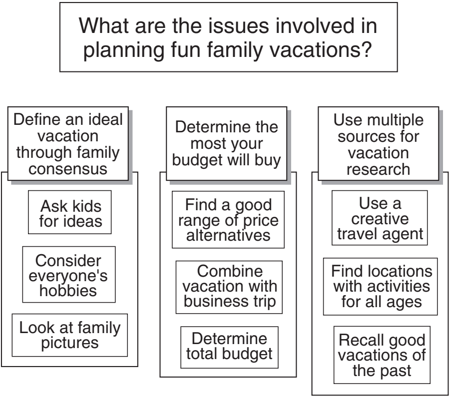


Illustration Note: There are 5 to 10 groupings of ideas in a typical Affinity. This is a partial Affinity.

Tip Spend the extra time needed to do solid header cards. Strive to capture the essence of *all* of the ideas in each grouping. ***Shortcuts here can greatly reduce the effectiveness of the final Affinity Diagram.***

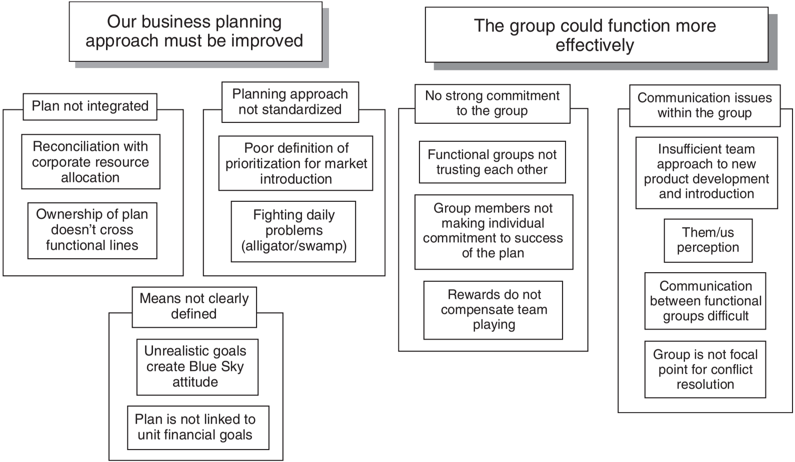
It is possible that a note within a grouping could become a header card. However, don't choose the "closest one" because it's convenient. The hard work of creating new header cards often leads to breakthrough ideas.

Variations

Another popular form of this tool, called the KJ Method, was developed by the Japanese anthropologist Jiro Kawakita while he was doing fieldwork in the 1950s. The KJ Method, identified with Kawakita's initials, helped the anthropologist and his students gather and analyze data. The KJ Method differs from the Affinity Diagram described above in that the cards are fact-based and go through a highly structured refinement process before the final diagram is created.

Affinity

Issues Surrounding Implementation of the Business Plan



Our business planning approach must be improved

- Plan not integrated
  - Reconciliation with corporate resource allocation
  - Ownership of plan doesn't cross functional lines
- Planning approach not standardized
  - Poor definition of prioritization for market introduction
  - Fighting daily problems (alligator/swamp)
- Means not clearly defined
  - Unrealistic goals create Blue Sky attitude
  - Plan is not linked to unit financial goals

The group could function more effectively

- No strong commitment to the group
  - Functional groups not trusting each other
  - Group members not making individual commitment to success of the plan
  - Rewards do not compensate team playing
- Communication issues within the group
  - Insufficient team approach to new product development and introduction
  - Them/us perception
  - Communication between functional groups difficult
  - Group is not focal point for conflict resolution

Information provided courtesy of Goodyear

More groupings on next page

Issues Surrounding Implementation of the Business Plan (cont.)

External factors impact implementation

- New government regulations
- Possibility of economic downturn

Limited resources are a challenge

- Fast new product introductions stretch resources
  - Lack integration of support group plans
  - Faster pace of product introductions stretches resources
- Lack of time and resources
  - Complexity driven by customer demands requires added investment
  - Capital availability limits opportunities
- Capacity may not meet needs
  - Sales forecast is not accurate
  - Production capacity
  - Production capability to support changing requirements

Information provided courtesy of Goodyear

Note: The Affinity helped the team bring focus to the *many* opinions on business planning. The headers that surfaced became the key issues in the ID example (shown in the Interrelationship Digraph tool section).

Brainstorming

Creating bigger
& better ideas

Why use it?

To establish a common method for a team to creatively and efficiently generate a high volume of ideas on any topic by creating a process that is free of criticism and judgment.

What does it do?

- Encourages open thinking when a team is stuck in "same old way" thinking
- Gets all team members involved and enthusiastic so that a few people don't dominate the whole group
- Allows team members to build on each other's creativity while staying focused on their joint mission

How do I do it?

There are two major methods for brainstorming.

- *Structured*. A process in which each team member gives ideas in turn.
- *Unstructured.* A process in which team members give ideas as they come to mind.

  Either method can be done silently or aloud.

Structured

1. **The central brainstorming question is stated, agreed on, and written down for everyone to see**

   Be sure that everyone understands the question, issue, or problem. Check this by asking one or two members to paraphrase it before recording it on a flipchart or board.

2. **Each team member, in turn, gives an idea. No idea is criticized. Ever!**

   With each rotation around the team, any member can pass at any time. While this rotation process encourages full participation, it may also heighten anxiety for inexperienced or shy team members.

3. **As ideas are generated, write each one in large, visible letters on a flipchart or other writing surface**

   Make sure every idea is recorded with the same words of the speaker; don't interpret or abbreviate. To ensure this, the person writing should always ask the speaker if the idea has been worded accurately.

4. **Ideas are generated in turn until each person passes, indicating that the ideas (or members) are exhausted**

   Keep the process moving and relatively short—5 to 20 minutes works well, depending on how complex the topic is.

5. **Review the written list of ideas for clarity and to discard any duplicates**

   Discard only ideas that are virtually identical. It is often important to preserve subtle differences that are revealed in slightly different wordings.

Unstructured

The process is the same as in the structured method except that ideas are given by everyone at any time. There is no need to "pass" since ideas are not solicited in rotation.

Variations

There are many ways to stimulate creative team thinking. The common theme among all of them is the stimulation of creativity by taking advantage of the combined brain power of a team. Here are three examples:

- **Visual brainstorming.** Individuals (or the team) produce a picture of how they see a situation or problem.
- **Analogies/free-word association.** Unusual connections are made by comparing the problem to seemingly unrelated objects, creatures, or words. For example: "If the problem was an animal, what kind would it be?"
- **6-3-5 method.** This powerful, silent method is proposed by Helmut Schlicksupp in his book *Creativity Workshop.* It is done as follows:

  a) Based on a single brainstorming issue, each person on the team (usually six people) has five minutes to write down three ideas on a sheet of paper.

  b) Each person then passes his or her sheet of paper to the next person, who has five more minutes to add three more ideas that build on the first three ideas.

c) This rotation is repeated as many times as there are team members, e.g., six team members = six rotations, six sheets of paper, eighteen ideas per sheet.

This interesting process forces team members to consciously build on each other's perspectives and input.

Cause & Effect/ Fishbone Diagram

Find & cure causes, NOT symptoms

Why use it?

To allow a team to identify, explore, and graphically display, in increasing detail, all of the possible causes related to a problem or condition to discover its root cause(s).

What does it do?

- Enables a team to focus on the content of the problem, not on the history of the problem or differing personal interests of team members
- Creates a snapshot of the collective knowledge and consensus of a team around a problem. This builds support for the resulting solutions.
- Focuses the team on causes, not symptoms

How do I do it?

1. **Select the most appropriate cause & effect format. There are two major formats:**
    - **Dispersion Analysis Type** is constructed by placing individual causes within each "major" cause category and then asking of each individual cause "Why does this cause (dispersion) happen?" This question is repeated for the next level of detail until the team runs out of causes. The graphic examples shown in Step 3 of this tool section are based on this format.

- **Process Classification Type** uses the major steps of the process in place of the major cause categories. The root cause questioning process is the same as the Dispersion Analysis Type.

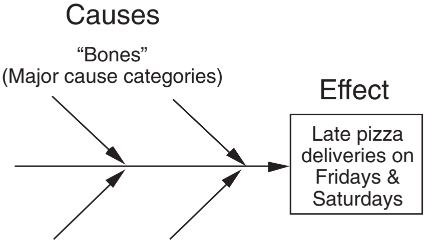
2. **Generate the causes needed to build a Cause & Effect Diagram. Choose one method:**

- **Brainstorming** without previous preparation.
- **Check Sheets** based on data collected by team members before the meeting.

3. **Construct the Cause & Effect/Fishbone Diagram**

a) Place the problem statement in a box on the righthand side of the writing surface.

- Allow plenty of space. Use a flipchart sheet, butcher paper, or a large white board. A paper surface is preferred since the final Cause & Effect Diagram can be moved.



Tip Make sure everyone agrees on the problem statement. Include as much information as possible on the "what," "where," "when," and "how much" of the problem. Use data to specify the problem.

b) Draw major cause categories or steps in the production or service process. Connect them to the "backbone" of the fishbone chart.

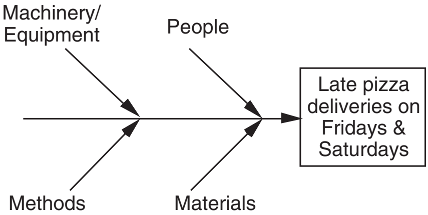
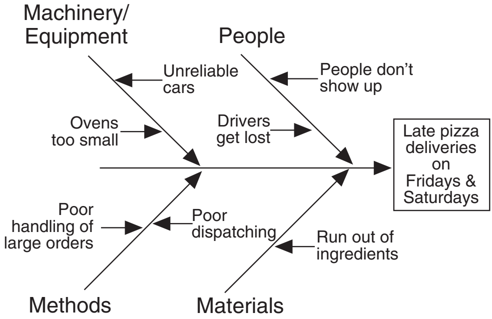


Illustration Note: In a Process Classification Type format, replace the major "bone" categories with: "Order Taking," "Preparation," "Cooking," and "Delivery."

- Be flexible in the major cause "bones" that are used. In a **Production Process** the traditional categories are: **Machines** (equipment), **Methods** (how work is done), **Materials** (components or raw materials), and **People** (the human element). In a **Service Process** the traditional methods are: **Policies** (higher-level decision rules), **Procedures** (steps in a task), **Plant** (equipment and space), and **People**. In both types of processes, **Environment** (buildings, logistics, and space) and **Measurement** (calibration and data collection) are also frequently used. ***There is no perfect set or number of categories. Make them fit the problem.***



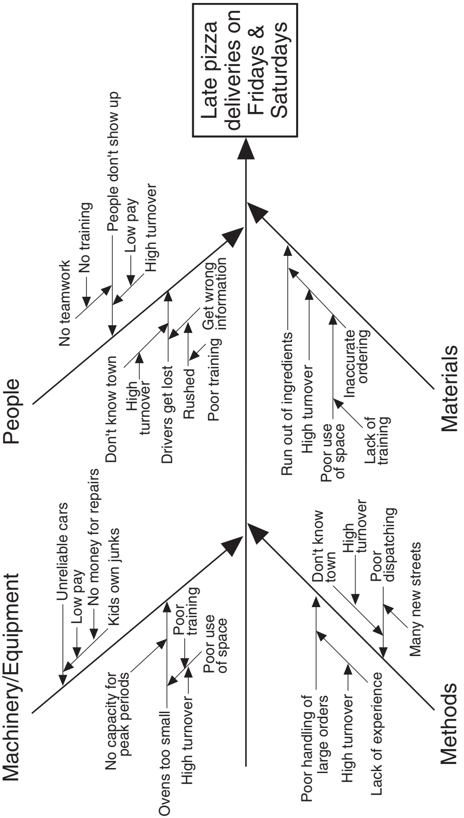
c) Place the brainstormed or data-based causes in the appropriate category.

- In brainstorming, possible causes can be placed in a major cause category as each is generated, or only after the entire list has been created. Either works well but brainstorming the whole list first maintains the creative flow of ideas without being constrained by the major cause categories or where the ideas fit in each "bone."
- Some causes seem to fit in more than one category. Ideally each cause should be in only one category, but some of the "people" causes may legitimately belong in two places. Place them in both categories and see how they work out in the end.

Tip If ideas are slow in coming, use the major cause categories as catalysts, e.g., "What in 'materials' is causing . . . ?"

d) Ask repeatedly of each cause listed on the "bones," either:

- "Why does it happen?" For example, under "Run out of ingredients" this question would lead to more basic causes such as “Inaccurate ordering,” “Poor use of space,” and so on.



- "What could happen?" For example, under "Run out of ingredients" this question would lead to a deeper understanding of the problem such as "Boxes," "Prepared dough," "Toppings," and so on.

Tip For each deeper cause, continue to push for deeper understanding, but know when to stop. A rule of thumb is to stop questioning when a cause is controlled by more than one level of management removed from the group. Otherwise, the process could become an exercise in frustration. Use common sense.

e) Interpret or test for root cause(s) by one or more of the following:

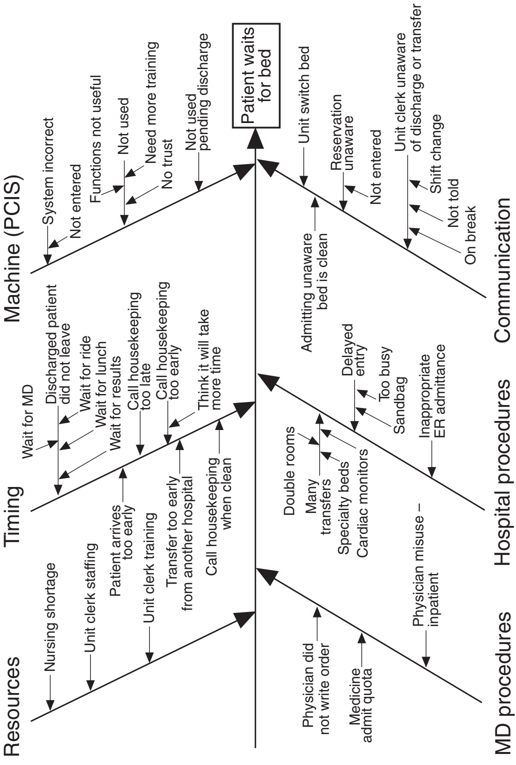
- Look for causes that appear repeatedly within or across major cause categories.
- Select through either an unstructured consensus process or one that is structured, such as Nominal Group Technique or Multivoting.
- Gather data through Check Sheets or other formats to determine the relative frequencies of the different causes.

Variations

Traditionally, Cause & Effect Diagrams have been created in a meeting setting. The completed "fishbone" is often reviewed by others and/or confirmed with data collection. A very effective alternative is CEDAC®, in which a large, highly visible, blank fishbone chart is displayed prominently in a work area. Everyone posts both potential causes and solutions on Post-it® Notes in each of the categories. Causes and solutions are reviewed, tested, and posted. This technique opens up the process to the knowledge and creativity of every person in the operation.

Cause & Effect/Fishbone

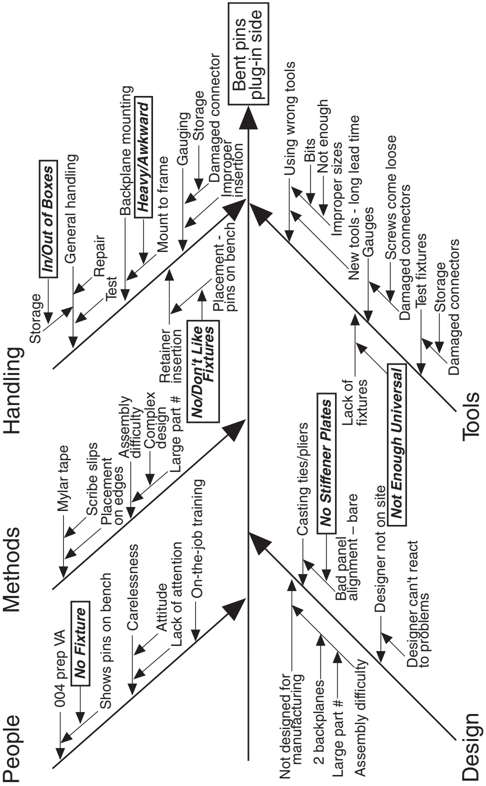
Bed Assignment Delay



Information provided courtesy of Rush-Presbyterian-St. Luke's Medical Center

Cause & Effect/Fishbone

Causes for Bent Pins (Plug-In Side)



Information provided courtesy of AT&T

Five Whys

This method helps you determine root causes quickly. Start with your focused problem and then ask "Why?" five times.

Example

Focused problem: Customers complain about waiting too long to get connected to staff when they call during lunch hours.

A Sample Implementation of the Five Whys Method

Sample focused problem: Customers complain about waiting too long to get connected to staff when they call during lunch hours.

The first three whys are progressively deeper, more specific, actionable causes. The problem-solving team should focus on the third why.

- **Why** does this problem happen?
  Backup operators take longer to connect callers.
  - **Why** does it take backup operators longer?
    Backup operators don't know the job as well as the regular operators/receptionists do.
    - **Why** don't the backup operators know the job as well?
      There is no special training or job aids to make up for the gap in experience, and they receive all their training on the job.

These broader causes are outside the scope of the problem-solving team and should be provided to management as data about systems issues that are deep causes of problems.

- **Why** don't they have special training or job aids?
  In the past, the organization has not recognized this need.
  - **Why** hasn't the organization recognized this need?
    The organization has no system to identify training needs.

Tip As you probe down five or more levels, you might come up with different solution ideas that fit for each level. Where should you stop? What is the level at which you could take action?

- It depends on the scope of authority of the person or team investigating the problem.
- An immediate fix for the example on the previous page would be to provide at least some training for current backup operators.

As you push for deeper whys, record all of your ideas. You can then arrange them using another tool. This usually doesn't help directly with the problem you are addressing, but top management can use the data from a series of problems to address system and policy issues.

Charter

Framing the DMAIC project

Why use it?

To obtain an agreement between management and project team members about what the team will accomplish.

What does it do?

- Clarifies what is expected of the team
- Keeps the team focused
- Keeps the team aligned with organizational priorities
- Transfers ownership of the project from the leadership team and sponsor(s) to the project team

How do I do it?

Some charters are long and detailed; others are short and concise. All charters should include the elements listed below. Complete the six steps outlined below to create your charter. (See pages 13 through 17 of *The Project Management Memory Jogger*™ for a sample charter. Another sample charter starts on page 63.)

1. **Develop an overview of the purpose of your project.**
   - The purpose describes the problem or opportunity your team is addressing.
   - The purpose answers the question "What is wrong?"

- Focus on what the team's goals are.
- The purpose should not include assumptions about causes of the problem or possible solutions.
- Additional questions to ask include the following:
  - What is important to customers about our product or service?
  - What problems do customers have with our product or service?
  - What problem is our team addressing?

2. **Develop one or more statements about why it is important to work on this project**
   - Describe the business case for the project:
     - Why is it important to customers?
     - Why is it important to our business?
     - Why is it important to employees?
     - Why should it be worked on now?
   - Estimate the project's potential impact on your business or the potential opportunity it can create.
     - Rough figures are OK.
   - Additional questions to ask include the following:
     - How will the reduction of defects impact our customers? The business? The employees?

Tip Before they can fully commit to and support a project, the sponsors need to have at least a rough estimate of the project's business impact. They then have the opportunity to either buy into the project or suggest revisions in scope or direction that will improve the project's impact.

3. **Identify the *focus*, or *scope*, of the project. Scope does the following:**
   - Identifies the boundaries of the team's work: the start and end points of the process the team is improving, the stage at which project team members begin their work, and the stage at which their work ends.
   - Clarifies decision-making authority.
   - Clarifies budgetary limits.
   - Clarifies what is within the team's area of influence—as well as what is outside that area.
   - Includes the project's schedule and milestones.
   - Includes identifying checkpoints, or "tollgates," as reminders for the team to check with the sponsors at each major milestone.
   - Additional questions to ask include the following:
     - How will the team focus its work?
     - What information will you collect to identify urgent problems?
     - What specific parts of the process will you focus on?
4. **Determine the specific deliverables to be produced during the project**
   - The final deliverable goes to the customers of the project.
   - This deliverable can be a product, service, process, or plan.
   - A deliverable can be regarded as something that must be in place before changes can be accomplished.

- The types of deliverables for most projects are very similar. They include:
  - Process changes.
  - Training.
  - Documentation.
  - Other processes and procedures for maintaining gains.

5. **Define the measures or other indicators that will be used to (a) judge the success of the project and (b) identify ways to improve performance at a later date**
   - These measures/indicators do the following:
     - Establish a baseline of performance.
     - Are used to track progress.
     - Are used to judge the project's success.
   - If possible, identify the target and specifications for each measure.
   - Additional questions to ask include:
     - How much improvement is needed?
     - What defects will you be tracking?

6. **Determine the resources available to the team**
   - These resources consist primarily of the people who are available to join the team and do its work.
     - Include how much time they can spend on the project.
     - If they cannot be on the team, state the circumstances under which they can be involved with the project.
   - You can also include people who are not members of the team but might be called upon

by the team for additional information and expertise.

- Additional questions to ask include:
  - To whom is the team accountable?
  - Who is the team leader?
  - To whom can the team turn for expert guidance and coaching?
  - Has the process owner been identified?

Tip Every project needs a charter! If your sponsor has not provided it, then create one and get it approved.

Tip Write the charter in such a way that someone completely unfamiliar with the project could read it and understand what the project involves and why you are working on it.

Tip Most projects evolve; during each step, you learn more about what is really going on. Be open to revisiting the scope, definition, and purpose of your project. Check with your sponsor before making any substantive changes.

Sample Charter

Purpose

- Customers complain that it is frustrating to be unable to reach the appropriate party quickly when they call in. The Connect Time Team's purpose is to eliminate long waits for callers while they are being connected to their desired parties.

Importance

- *Customer Satisfaction*
  This is one of our four corporate strategic objectives.

How a phone call is handled is one of the first impressions a customer gets of our company. Surveys of customer satisfaction show "long wait time" as the #2 concern, second only to our pricing. Total elimination of this dissatisfier would increase overall satisfaction by 8 points. We assume a 50% improvement. Each point of satisfaction correlates with a revenue gain of $100,000 annually. $100,000 × 4 points = $400,000/year.

- *Revenue Increase*
  In addition to the revenue described above, we anticipate increased sales by having fewer potential customers drop off (i.e., hang up) while waiting for us to answer their calls. We average five hang-ups daily. Each caller orders an average of $400. We assume a 50% improvement. Five calls/day × $400/call × 250 days/year × 50% = $250,000/year.

Scope

- The team should focus its work on the process that takes place from the time a phone call comes in to the company until an appropriate person answers it. The team should consider ways to improve the operations of the current phone system—not investigate purchasing a new system.
- The team has authority to recommend solutions, including the purchase of new equipment, but it must get approval for all proposed solutions from its sponsors and the Operations Team. The office manager must approve any funding the team needs.

Measures

- A defect is considered to be a connection time of greater than thirty seconds.
- The team will be measured on its ability to reduce the time it takes to connect callers to a person who can help them with their questions. This will be tracked by following random calls through the process.

Deliverables

- The team should complete its work by February 15 and give a presentation to the Management Team.
- Develop and implement an improved process for connecting calls.
- Create a training program for the new process for all employees using existing communication channels.
- Provide a plan for ongoing monitoring and improvement of the process.

Resources

- *Team Sponsors*: Fred Smith, John Drucker
- *Team Members*: Ellen Hajduk, Customer Service Operator (Team Leader)

  Marjorie Andersen, Customer Service Operator
  Harry Cheng, Customer Service Operator
  Antonio Soto Diaz, Engineering
  Charmaine Jackson, Accounting
  Mary Scott, Information Services
  Mandy O'Neill, Sales and Service Supervisor
- *Coach*: Melissa Grant
- *Process Owner*: Kobe Oneal

- If the team decides it needs additional expertise, it must first check with the supervisor of the person with whom it wants to work.
- The team should not meet in excess of six hours per week without prior authorization from team members' supervisors.

Commitment Scale

Helping people commit to change

Why use it?

To identify and secure the support of, and remove the resistance of, people and systems vital to the accomplishment of the work.

What does it do?

- Identifies people or groups involved in or affected by a change
- Explicitly states the level of commitment required by each person or group before you can implement the change successfully
- Identifies the amount of work needed to bring people or groups to the level of commitment needed for you to implement the changes successfully
- Helps you set priorities and develop appropriate communication plans for different people or groups

A Sample Commitment Scale

	People or Groups		
Level of Commitment	Sales	Mgmt.	Cust.
Enthusiastic Will work hard to make it happen	●		●
Helpful Will lend appropriate support	↑	●	↑
Hesitant Holds some reservations; won't volunteer	↑	↑	↑
Indifferent Won't help; won't hurt	↑	↑	X
Uncooperative Will have to be prodded	↑	X	
Opposed Will openly state and act on opposition	X		
Hostile Will block at all costs			

How do I do it?

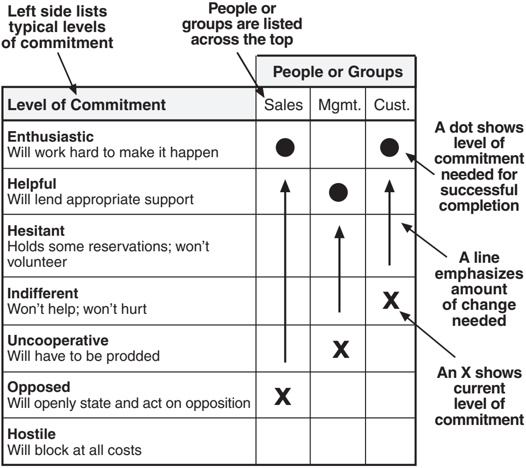
1. Identify the stakeholders involved in your project. Stakeholders are people who will be affected by the project or can influence it but are not directly involved with the project work.

2. List the stakeholder groups across the top of the commitment scale

3. Agree on the level of commitment needed by each stakeholder group for successful completion of the project. Indicate the level needed with a dot.

4. Agree on the current level of commitment of each stakeholder group. Indicate the current level with an X.
5. As a team, discuss the amount of change required to address any gaps between the current and required commitment levels
6. Develop a communication and action plan to address these gaps

The Components of a Commitment Scale



	People or Groups		
Level of Commitment	Sales	Mgmt.	Cust.
Enthusiastic Will work hard to make it happen	●		●
Helpful Will lend appropriate support	↑	●	↑
Hesitant Holds some reservations; won't volunteer	↑	↑	↑
Indifferent Won't help; won't hurt	↑	↑	X
Uncooperative Will have to be prodded	↑	X	
Opposed Will openly state and act on opposition	X		
Hostile Will block at all costs			

Left side lists typical levels of commitment

People or groups are listed across the top

A dot shows level of commitment needed for successful completion

A line emphasizes amount of change needed

An X shows current level of commitment

Communication Plan

Keeping people informed about the project

Why use it?

To plan how you will communicate with stakeholders for the duration of the project.

What does it do?

- Helps you identify and secure the support of, and remove the resistance of, people and systems vital to the accomplishment of the work
- Creates more buy-in
- Helps the team avoid pitfalls
- Identifies people or groups involved in or affected by a change
- Provides a vehicle for sharing the lessons learned from the project

How do I do it?

1. **During the Define step of the DMAIC method, identify the stakeholders involved in your project. Stakeholders are people who will be affected by the project or can influence it but are not directly involved with the project work.**
   - Typical stakeholders include the following:
     - – Managers whose budgets, results, schedules, or resources will be affected by the project.
     - – Process owners.
     - – People who work on the process that you are studying.

- Internal departments or groups whose work feeds into the process or whose work depends on the process.
- Customers who purchase or use the output (i.e., the product or service) of the process.
- Suppliers who provide materials or services used by the process.
- Your organization's financial department.

2. **Identify the main concerns each group of stakeholders might have regarding the project**

3. **Develop a plan to give each group of stakeholders a report on the project's progress and to address their main concerns**

A Sample Communication Plan

Role	**Who** Names of people or groups	**Main Concerns**	**Communication Notes** When and how you will communicate with them
Team Leader (Six Sigma Expert) (If someone other than yourself)			
Team Member			
Sponsor(s)			
Team Coach (Master Six Sigma Expert)			
Process Owner			
Customers			
Other Stakeholders			

4. **Throughout the project, continue to regularly communicate with these stakeholder groups**

5. **Conduct "tollgate" reviews, which are formal reviews of the project's progress that are done at major milestones. Typically, tollgate reviews are conducted after each step in the DMAIC method.**

6. **When the team begins the Control step of the DMAIC method, plan for communication, closure, and recognition**

   - Summarize learnings.
     - About the work process:
       - What did you learn about the process that surprised you?
       - How much variation was in the process when your project began?
       - Are there other, similar processes in your organization?
     - About the team's process:
       - What did you learn about conducting a Six Sigma project?
       - What did you learn about working on a team? How well did team members work together?
       - What advice would you give to other teams?
       - How well did you work with your sponsor?
     - About your results:
       - Did you accomplish your mission? What factors helped your team? What factors hindered it?
       - What were your technical or business accomplishments?
       - Have the improvements been standardized and error-proofed? How will the improvements

    be maintained? How were they communicated within and between work groups?

    - What other discoveries did you make? How were they communicated within and between work groups?
    - Have you used the PDCA Cycle on the changes you made?

Tip If time allows, or if there is a large volume of stakeholder concerns, you might want to use an Affinity Diagram to organize your team's list of ideas and brainstorm to decide what to do next. Then you can present the themes you identify to management and coworkers.

- Finalize documentation on improvements.
  - Finish your storyboard. It should contain your final results and conclusions.
  - Present the completed document to:
    - The sponsors.
    - The people whose jobs will change as a result of the work.
    - Customers affected by the change.
    - The stakeholders.
  - Collect and catalog the documentation and make it available to others.
- Summarize future plans and recommendations.
  - Have your team discuss the following issues and compile recommendations to submit to your sponsor or guidance team.
    - What are your recommendations for maintaining the gains already put in place? What role would you like your team to play?

    - How much improvement is still needed to achieve your company's business goals?
    - What parts of the problem still need to be addressed? Which are the most urgent?
    - What would your team like to work on next, if approved by management? Where do you think management should devote company resources next?

- Communicate the results and future plans.
  - – Communicating the team's results is a joint task for the project team and their sponsor.
    - If you haven't done so already, identify the people who will be involved in implementing the improved methods.
    - Which other employees could benefit from the lessons you learned?
    - How can you convey your team's results to management? To the rest of the organization?
    - How can the end of this project sow the seeds for future projects?

Tip When your team completes the Control step of the DMAIC method, you should be able to show your sponsor the following:

- Completed project documentation. Include a final storyboard that shows the results of your data analysis.
- Recommendations—supported by data, if possible—for next actions involving this process or ideas for a spin-off from this project.
- Plans for, or results from, communicating your achievements to the rest of the organization.
- Plans for celebrating your success.

Control Charts

Recognizing
sources of variation

Why use it?

To monitor, control, and improve process performance over time by studying variation and its source.

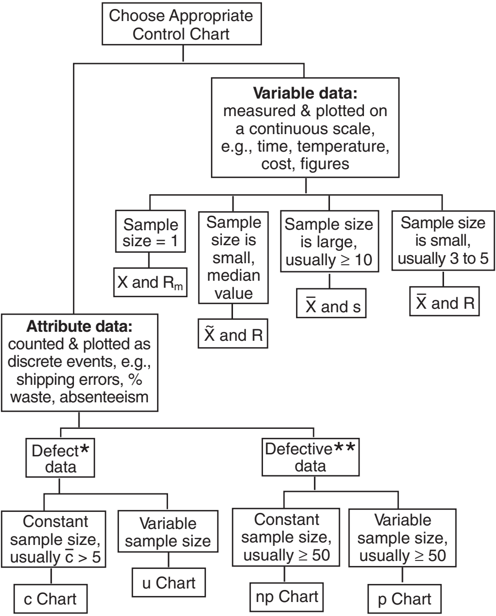
What does it do?

- Focuses attention on detecting and monitoring process variation over time
- Distinguishes special from common causes of variation, as a guide to local or management action
- Serves as a tool for ongoing control of a process
- Helps improve a process to perform consistently and predictably for higher quality, lower cost, and higher effective capacity
- Provides a common language for discussing process performance

How do I do it?

There are many types of Control Charts. The Control Chart(s) that your team decides to use will be determined by the type of data you have. Use the Tree Diagram on the next page to determine which Control Chart(s) will best fit your situation. Other types of Control Charts, which are beyond the scope of this book, include the Pre-Control Chart, the Moving Average & Range Chart, and the Cumulative Sum Chart.

Based on the type of data and sample size you have, choose the appropriate Control Chart.



* Defect = Failure to meet one of the acceptance criteria. A defective unit might have multiple defects.

** Defective = An entire unit fails to meet acceptance criteria, regardless of the number of defects on the unit.

Constructing Control Charts

1. **Select the process to be charted**

2. **Determine sampling method and plan**
   - How large a sample can be drawn? Balance the time and cost to collect a sample with the amount of information you will gather. ***See the Tree Diagram on the previous page for suggested sample sizes.***
   - As much as possible, obtain the samples under the same technical conditions: the same machine, operator, lot, and so on.
   - Frequency of sampling will depend on whether you are able to discern patterns in the data. Consider hourly, daily, shifts, monthly, annually, lots, and so on. Once the process is "in control," you might consider reducing the frequency with which you sample.
   - Generally, collect 20–25 groups of samples before calculating the statistics and control limits.
   - Consider using historical data to set a baseline.

   Tip Make sure samples are random. To establish the inherent variation of a process, allow the process to run untouched, i.e., according to standard procedures.

3. **Initiate data collection**
   - Run the process untouched, and gather sampled data.
   - Record data on an appropriate Control Chart sheet or other graph paper. Include any unusual events that occur.

4. Calculate the appropriate statistics

a) If you have attribute data, use the Attribute Data Table, Central Line column.

Attribute Data Table

Type Control Chart	Sample size	Central Line	Control Limits
Fraction defective p Chart	Variable, usually ≥50	For each subgroup: $p = np/n$ For all subgroups: $\bar{p} = \Sigma np/\Sigma n$	$^*UCL_p = \bar{p} + 3\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$ $^*LCL_p = \bar{p} - 3\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$
Number defective np Chart	Constant, usually ≥50	For each subgroup: np = # defective units For all subgroups: $n\bar{p} = \Sigma np/k$	$UCL_{np} = n\bar{p} + 3\sqrt{n\bar{p}(1 - \bar{p})}$ $LCL_{np} = n\bar{p} - 3\sqrt{n\bar{p}(1 - \bar{p})}$
Number of defects c Chart	Constant	For each subgroup: c = # defects For all subgroups: $\bar{c} = \Sigma c/k$	$UCL_c = \bar{c} + 3\sqrt{\bar{c}}$ $LCL_c = \bar{c} - 3\sqrt{\bar{c}}$
Number of defects per unit u Chart	Variable	For each subgroup: $u = c/n$ For all subgroups: $\bar{u} = \Sigma c/\Sigma n$	$^*UCL_u = \bar{u} + 3\sqrt{\frac{\bar{u}}{n}}$ $^*LCL_u = \bar{u} - 3\sqrt{\frac{\bar{u}}{n}}$

np = # defective units
c = # of defects
n = sample size within each subgroup
k = # of subgroups

* This formula creates changing control limits. To avoid this, use average sample sizes $\bar{n}$ for those samples that are within ±20% of the average sample size. Calculate individual limits for the samples exceeding ±20%.

b) If you have variable data, use the Variable Data Table, Central Line column.

Variable Data Table

Type Control Chart	Sample size n	Central Line*	Control Limits
Average & Range	<10, but usually 3 to 5	$\bar{\bar{X}} = \frac{(\bar{X}_1+\bar{X}_2+\ldots\bar{X}_k)}{k}$	$UCL_{\bar{x}} = \bar{\bar{X}} + A_2\bar{R}$ $LCL_{\bar{x}} = \bar{\bar{X}} - A_2\bar{R}$
$\bar{X}$ and R		$\bar{R} = \frac{(R_1+R_2+\ldots R_k)}{k}$	$UCL_R = D_4\bar{R}$ $LCL_R = D_3\bar{R}$
Average & Standard Deviation	Usually ≥10	$\bar{\bar{X}} = \frac{(\bar{X}_1+\bar{X}_2+\ldots\bar{X}_k)}{k}$	$UCL_{\bar{x}} = \bar{\bar{X}} + A_3\bar{s}$ $LCL_{\bar{x}} = \bar{\bar{X}} - A_3\bar{s}$
$\bar{X}$ and s		$\bar{s} = \frac{(s_1+s_2+\ldots s_k)}{k}$	$UCL_s = B_4\bar{s}$ $LCL_s = B_3\bar{s}$
Median & Range	<10, but usually 3 or 5	$\bar{\tilde{X}} = \frac{(\tilde{X}_1+\tilde{X}_2+\ldots\tilde{X}_k)}{k}$	$UCL_{\tilde{x}} = \bar{\tilde{X}} + \tilde{A}_2\bar{R}$ $LCL_{\tilde{x}} = \bar{\tilde{X}} - \tilde{A}_2\bar{R}$
$\tilde{X}$ and R		$\bar{R} = \frac{(R_1+R_2+\ldots R_k)}{k}$	$UCL_R = D_4\bar{R}$ $LCL_R = D_3\bar{R}$
Individuals & Moving Range	1	$\bar{X} = \frac{(X_1+X_2+\ldots X_k)}{k}$	$UCL_X = \bar{X} + E_2\bar{R}_m$ $LCL_X = \bar{X} - E_2\bar{R}_m$
X and R_m		$R_m = \lvert(X_{i+1} - X_i)\rvert$ $\bar{R}_m = \frac{(R_1 + R_2 + \ldots R_{k-1})}{k-1}$	$UCL_{Rm} = D_4\bar{R}_m$ $LCL_{Rm} = D_3\bar{R}_m$

k = # of subgroups, $\tilde{X}$ = median value within each subgroup

*$\bar{X} = \frac{\Sigma X_i}{n}$

5. Calculate the control limits

a) If you have attribute data, use the Attribute Data Table, Control Limits column.

b) If you have variable data, use the Variable Data Table, Control Limits column for the correct formula to use.

- Use the Table of Constants to match the numeric values to the constants in the formulas shown in the Control Limits column of the Variable Data Table. The values you will need to look up will depend on the type of Variable Control Chart you choose and on the size of the sample you have drawn.

Tip If the Lower Control Limit (LCL) of an Attribute Data Control Chart is a negative number, set the LCL to zero.

Tip The p and u formulas create changing control limits if the sample sizes vary subgroup to subgroup. To avoid this, use the average sample size, $\bar{n}$, for those samples that are within ±20% of the average sample size. Calculate individual limits for the samples exceeding ±20%.

6. Construct the Control Chart(s)

- For Attribute Data Control Charts, construct one chart, plotting each subgroup's proportion or number defective, number of defects, or defects per unit.
- For Variable Data Control Charts, construct two charts: on the top chart plot each subgroup's mean, median, or individuals, and on the bottom chart plot each subgroup's range or standard deviation.

Table of Constants

Sample size n	$\bar{X}$ and R Chart			$\bar{X}$ and s Chart			
	A_2	D_3	D_4	A_3	B_3	B_4	c_4*
2	1.880	0	3.267	2.659	0	3.267	.7979
3	1.023	0	2.574	1.954	0	2.568	.8862
4	0.729	0	2.282	1.628	0	2.266	.9213
5	0.577	0	2.114	1.427	0	2.089	.9400
6	0.483	0	2.004	1.287	0.030	1.970	.9515
7	0.419	0.076	1.924	1.182	0.118	1.882	.9594
8	0.373	0.136	1.864	1.099	0.185	1.815	.9650
9	0.337	0.184	1.816	1.032	0.239	1.761	.9693
10	0.308	0.223	1.777	0.975	0.284	1.716	.9727

Sample Size n	$\tilde{X}$ and R Chart			X and R_m Chart			
	$\tilde{A}_2$	D_3	D_4	E_2	D_3	D_4	d_2*
2	- - - -	0	3.267	2.659	0	3.267	1.128
3	1.187	0	2.574	1.772	0	2.574	1.693
4	- - - -	0	2.282	1.457	0	2.282	2.059
5	0.691	0	2.114	1.290	0	2.114	2.326
6	- - - -	0	2.004	1.184	0	2.004	2.534
7	0.509	0.076	1.924	1.109	0.076	1.924	2.704
8	- - - -	0.136	1.864	1.054	0.136	1.864	2.847
9	0.412	0.184	1.816	1.010	0.184	1.816	2.970
10	- - - -	0.223	1.777	0.975	0.223	1.777	3.078

* Useful in estimating the process standard deviation $\hat{\sigma}$.

Note: The minimum sample size shown in this chart is 2 because variation in the form of a range can only be calculated in samples greater than 1. The X and R_m Chart creates these minimum samples by combining and then calculating the difference between sequential, individual measurements.

- Draw a solid horizontal line on each chart. This line corresponds to the process average.
- Draw dashed lines for the upper and lower control limits.

Interpreting Control Charts

- **Attribute Data Control Charts** are based on one chart. The charts for fraction or number defective, number of defects, or number of defects per unit measure variation *between samples*. **Variable Data Control Charts** are based on two charts: the one on top, for averages, medians, and individuals, measures variation *between subgroups* over time; the chart below, for ranges and standard deviations, measures variation *within subgroups* over time.
- Determine if the process mean (center line) is where it should be relative to your customer specification or your internal business objective. If not, then it is an indication that your process is not currently capable of meeting the objective.
- Analyze the data relative to the control limits, distinguishing between *common* causes and *special* causes. The fluctuation of the points within the limits results from variation inherent in the process. This variation results from common causes within the system, e.g., design, choice of machine, preventive maintenance, and can only be affected by changing that system. However, points outside of the limits or patterns within the limits come from a special cause, e.g., human errors, unplanned events, freak occurrences, that is not part of the way the process normally operates, or is present because of an unlikely combination of process steps. Special causes must

be eliminated before the Control Chart can be used as a monitoring tool. Once this is done, the process will be "in control" and samples can be taken at regular intervals to make sure that the process doesn't fundamentally change. See "Determining if Your Process is Out of Control."

- Your process is in "statistical control" if the process is not being affected by special causes. All the points must fall within the control limits, and they must be randomly dispersed about the average line for an in-control system.

Tip "Control" doesn't necessarily mean that the product or service will meet your needs. It only means that the process is *consistent.* Don't confuse control limits with specification limits—specification limits are related to customer requirements, not process variation.

Tip Any points outside the control limits, once identified with a cause (or causes), should be removed and the calculations and charts redone. Points within the control limits, but showing indications of trends, shifts, or instability, are also special causes.

Tip When a Control Chart has been initiated and all special causes removed, continue to plot new data on a new chart, but DO NOT recalculate the control limits. As long as the process does not change, the limits should not be changed. Control limits should be recalculated only when a permanent, desired change has occurred in the process, and only using data *after* the change occurred.

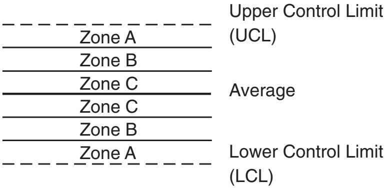
Tip Nothing will change just because you charted it! You need to do something. Form a team to investigate. See "Common Questions for Investigating an Out-of-Control Process."

Determining if Your Process Is "Out of Control"

A process is said to be "out of control" if either one of these is true:

1. **One or more points fall outside of the control limits**

2. **When the Control Chart is divided into zones, as shown below, any of the following points are true:**



   a) Two points, out of three consecutive points, are on the same side of the average in Zone A or beyond.

   b) Four points, out of five consecutive points, are on the same side of the average in Zone B or beyond.

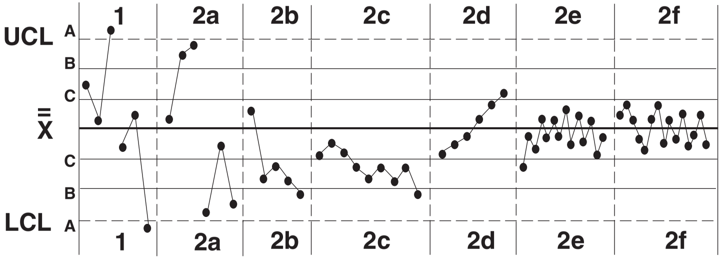
   c) Nine consecutive points are on one side of the average.

   d) There are six consecutive points, increasing or decreasing.

   e) There are fourteen consecutive points that alternate up and down.

   f) There are fifteen consecutive points within Zone C (above and below the average).

Tests for Control



Source: Lloyd S. Nelson, Director of Statistical Methods, Nashua Corporation, New Hampshire

Common Questions for Investigating an Out-of-Control Process

☐ Yes ☐ No Are there differences in the measurement accuracy of instruments/ methods used?

☐ Yes ☐ No Are there differences in the methods used by different personnel?

☐ Yes ☐ No Is the process affected by the environment, e.g., temperature, humidity?

☐ Yes ☐ No Has there been a significant change in the environment?

☐ Yes ☐ No Is the process affected by predictable conditions? Example: tool wear.

☐ Yes ☐ No Were any untrained personnel involved in the process at the time?

☐ Yes ☐ No Has there been a change in the source for input to the process? Example: raw materials, information.

☐ Yes ☐ No Is the process affected by employee fatigue?

☐ Yes ☐ No Has there been a change in policies or procedures? Example: maintenance procedures.

☐ Yes ☐ No Is the process adjusted frequently?

☐ Yes ☐ No Did the samples come from different parts of the process? Shifts? Individuals?

☐ Yes ☐ No Are employees afraid to report "bad news"?

A team should address each "Yes" answer as a potential source of a special cause.

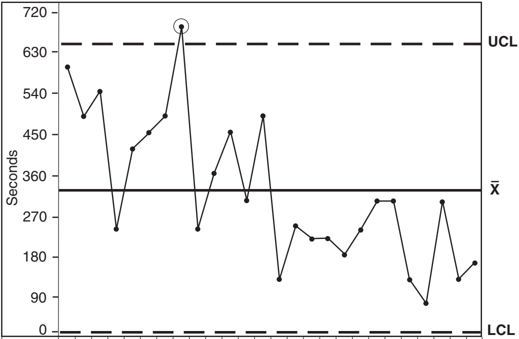
Individuals & Moving Range Chart

IV Lines Connection Time

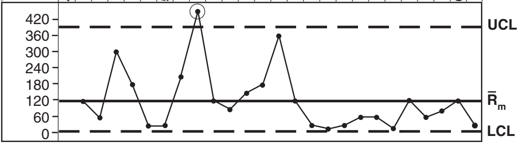
Process/Operation: IV Lines Connection Open Heart Admissions			**Department:** Intensive Care
Characteristic: Time in seconds	**Sample Size:** One	**Sample Frequency:** Each patient	**By:** EW **Date:** 6/10

Individuals: **k** = 26 ∑**X** = 8470 $\bar{X}$ = 325.77 **UCL** = 645 **LCL** = 7

Ranges: **n** = 2 ∑**R** = 2990 $\bar{R}$ = 119.6 **UCL** = 392 **LCL** = 0



X	600	480	540	240	420	450	480	690	240	360	450	300	480	120	240	210	210	180	240	300	300	130	120	300	180	210
R_m	—	120	60	300	180	30	30	210	450	120	90	150	180	360	120	30	0	30	60	60	0	120	60	80	120	30
Who?	EW	EW	EW	EW	EW	EW	EW	EW	MA	EW	EW	EW	EW	EW	EW	EW	MA	EW	EW	EW	EW	EW	EW	EW	EW	EW
When?	4/9	11	12	13	25	30	5/2	3	4	5	9	13	14	14	16	17	19	20	22	23	23	24	30	30	6/6	6



Information provided courtesy of Parkview Episcopal Medical Center

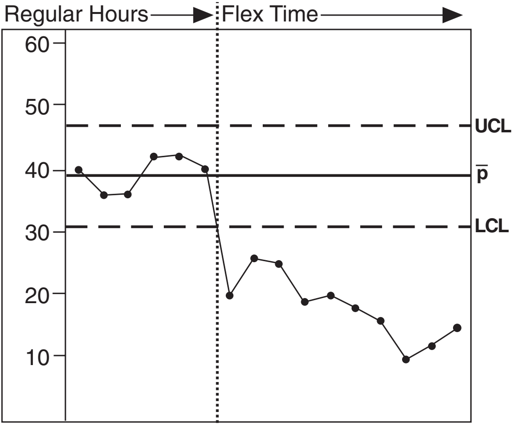
Note: Something in the process changed, and now it takes less time to make IV connections for patients being admitted for open heart surgery.

p Chart

General Dentistry: Percent of Patients Who Failed to Keep Appointments

Historical Statistics:

$\bar{p}$ = 39 **UCL** = 47 **LCL** = 31



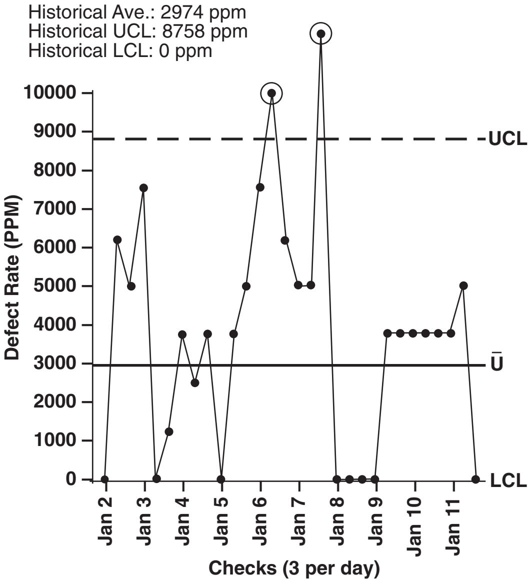
% Failed	40	36	36	42	42	40	20	26	25	19	20	18	16	10	12	12
Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Year	1992						1993									

Information provided courtesy of U.S. Navy, Naval Dental Center, San Diego

Note: Providing flex time for patients resulted in fewer appointments missed.

u Chart

Shop Process Check
Solder Defects

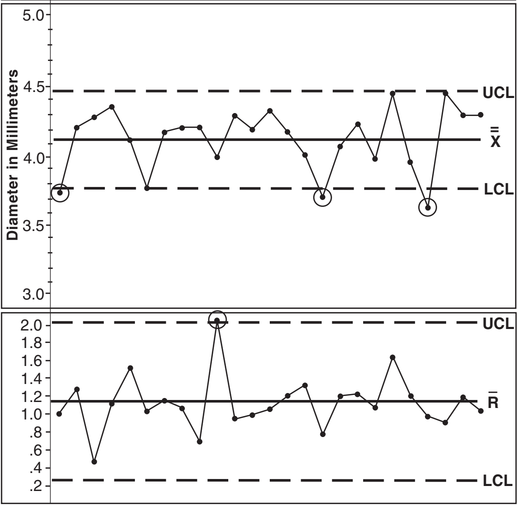


Information provided courtesy of AT&T

$\overline{X}$ & R Chart

n = 10 parts randomly sampled each hour

Hourly #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Ave.
$\overline{X}$	3.76	4.21	4.29	4.36	4.13	3.77	4.17	4.21	4.22	4.00	4.30	4.20	4.32	4.18	4.02	3.71	4.08	4.23	3.98	4.46	3.96	3.63	4.48	4.30	4.29	4.13
R	1.01	1.27	0.48	1.32	1.52	1.03	1.15	1.07	0.70	2.05	0.95	0.99	1.06	1.21	1.33	0.78	1.21	1.23	1.08	1.64	1.20	0.98	0.91	1.19	1.03	1.14



Information provided courtesy of BlueFire Partners, Inc., and Hamilton Standard

Note: Hours 1, 16, and 22 should be reviewed to understand why these sample averages are outside the control limts.

Critical To Quality (CTQ) Tree

Identifying measures from
the customer's perspective

Why use it?

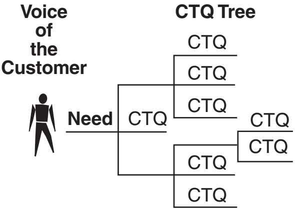
To identify Critical To Quality (CTQ) characteristics, features by which customers evaluate your product or service and that can be used as measures for your project. A useful CTQ characteristic has the following features:

- It is critical to the customer's perception of quality.
- It can be measured.
- A specification can be set to tell whether the CTQ characteristic has been achieved.

What does it do?

- Links customer needs gathered from your voice-of-the-customer (VOC) data-collection efforts with drivers and with specific, measurable characteristics
- Enables the project team to transform general data into specific data
- Makes the measuring process easier for the team

Setting Up a CTQ Tree

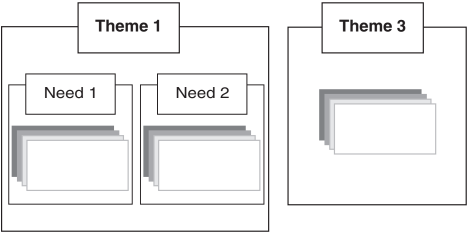


CTQ = Critical To Quality characteristics

How do I do it?

1. **Gather sorted customer needs from your data-collection process. The needs you use in the CTQ Tree can include the themes or specific needs from a Customer-Data Affinity Diagram (see below).**

A Customer-Data Affinity Diagram



Tip Use the Kano Model (see page 158) prior to identifying CTQs to ensure your team has not missed any critical customer needs.

2. **List the major customer needs from the Customer-Data Affinity Diagram on the left side of the CTQ Tree**

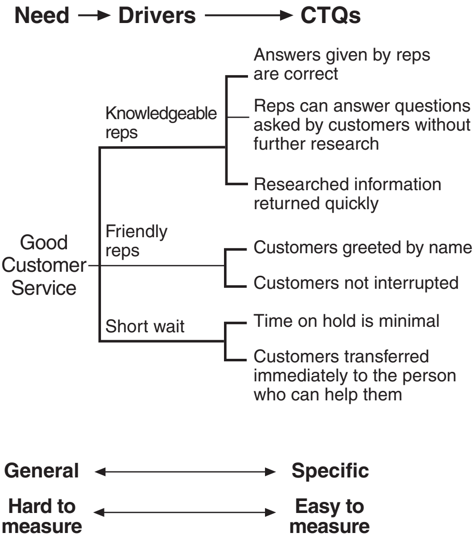
3. **Try to view each need from the customer's point of view. As you consider each need, ask, "What would that mean?" from the customer's standpoint. Each answer becomes a driver for the CTQs. Keep asking, "What would that mean?" until you reach a level where it would be absurd to continue. Your answers at this level are the CTQs.**

Example:

- "Good customer service" means "knowledgeable reps."

- "Knowledgeable reps" means the answers they give are correct.
- It would be absurd to ask what "correct answers" means, so you should stop at this point. "Correct answers" is an appropriate CTQ.

A Sample CTQ Tree



4. **Select CTQs for the project based on the following:**
   - Which will have the greatest positive impact on the customer?
   - Which are within your scope or process area of focus?
   - Which of the Kano Model's "Must Be" characteristics are not addressed? (See the section on the Kano Model.)

5. **During the Define, Measure, and Analyze steps of the DMAIC method, the team will develop the process-output measures directly affecting the CTQs you select. These process-output measures are called y's. The team will also develop the causal factors directly affecting the y's, called the x's.**

   Tip In some cases you can go directly from the customer needs to the CTQs, while in others you might need to drive down through several levels of the CTQ Tree to discover the underlying CTQs.

Data Collection

Gathering meaningful data

Why use it?

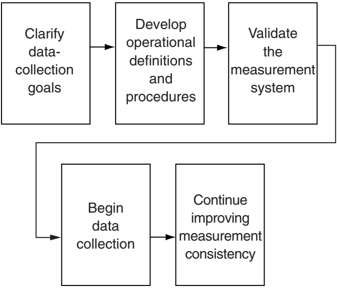
To help you collect the right data for your needs and ensure the data you collect is useful and meaningful.

What does it do?

- Saves your team time and effort. You do preliminary thinking about what data will help you understand and explain when—and under what conditions—a problem does and does not appear.
- Structures your data collection so everyone understands what data will be collected and how
- Helps you think about how you can sort your data in a manner that might provide clues about a problem's causes

How do I do it?

Data-Collection Steps



1. Clarify your data-collection goals

- Make sure the data you collect will give you the answers you need.
- Use the following questions to help you identify your data-collection goals.
  - Why are you collecting data? What questions do you want to answer?
  - What will you do with the data?
  - How will the data help you?
  - What patterns or relationships might you want to explore?
- Consider how you will stratify the data. *Stratification* means dividing data into groups, or strata, based on key characteristics.
  - A *key characteristic* is some aspect of the data that you think can help explain when, where, and/or why a problem exists.
  - The purpose of dividing data into groups is to detect a pattern that localizes a problem or explains why the problem's frequency or impact varies among different times, locations, or conditions.
- Typical stratification groups are based on the following:
  - Who—which people, groups, departments, or organizations are involved.
  - What—relevant machines, equipment, products, services, or supplies.
  - Where—the physical location of the defect or problem.
  - When—time of day, day of the week, or step of the process involved.

2. **Develop operational definitions and procedures. (See the section on Operational Definitions for details.)**

   Operational definitions tell you how you should measure something. They help you specify who should collect the data using what instrument, what data-collection form they should use, and whether they should measure each item or just a sample of the items.

   Sampling is useful when you don't need to collect data about every available occurrence to understand the process. Often you can learn much about a process from a relatively small amount of data. When sampling, take care to ensure that the sample represents all the data so that it gives an accurate, complete picture of the whole process. Your Six Sigma Expert should develop your sampling plan, which should specify what units to sample and how many samples to take.

3. **Validate the measurement system. (See the section on Measurement Systems Analysis for details.)**

4. **Begin data collection. This involves training the data collectors, piloting and error-proofing the data-collection process, and deciding how you will display your data.**

   Tip When the data-collection process begins, someone from the team who was involved in setting up the data-collection plan should be on hand to address any unanticipated issues that might arise.

5. **Continue improving your measurement consistency. Check to make sure that everyone is following the data-collection procedures and that you make changes as necessary to adapt to changing conditions.**

Tip Collecting data is a balancing act. You don't want your team to spend extra time collecting data because either you didn't get enough of it, or you didn't collect the right kind, in the first place. Conversely, you don't want to be buried in so much data that you cannot reasonably analyze or understand it given the time and methods available to you. Part of the challenge of data collection, therefore, is to decide just how much data will be sufficient and representative of the problem you wish to solve.

Tip If you already have experience with the DMAIC method and are familiar with the data tools, take time during this preliminary planning step to ensure you'll be able to analyze the data in ways that will answer your questions. Pretending you have the data in hand, make a sketch showing what an appropriate data plot looks like. Does it reveal the answers you need? For example, if you want to know if a problem is improving or worsening with time, you should use data that is collected in chronological order and suitable for plotting on Run Charts or Control Charts.

Tip For data collection involving voice-of-the-customer (VOC) data, see the section on VOC Data-Collection Systems and use the following VOC Data-Collection Plan Form.

Data-Collection Plan Form

Data-Collection Plan
PROJECT:

What questions do you want to answer?

Data		Operational Definition and Procedures			
What	Measure type/ data type	How measured[1]	Related conditions to record[2]	Sampling notes	How/where recorded (attach form)

How will you ensure consistency and stability?

What is your plan for starting data collection? (Attach details if necessary.)

Notes

[1] Include the unit of measurement where appropriate. Be sure to test and monitor any measurement procedures/ instruments.

[2] Related conditions are stratification factors or potential causes you want to monitor as you collect data.

How will the data be displayed? (Sketch on additional sheet.)

VOC Data-Collection Plan Form

VOC Data-Collection Plan
PROJECT:

Who	What and Why
Customers and Segments	Indicate specifically what you want to know about your customers. Develop customized versions of the following questions that you can ask during face-to-face interviews. • What's important to you? • What's a defect? • How are we doing? How do we compare to our competitors? • What do you like? What don't you like?

Sources

Put an X next to the data sources you think will be useful for this project.

Reactive Sources

- ☐ Complaints
- ☐ Problem or service hotlines
- ☐ Technical-support calls
- ☐ Customer-service calls
- ☐ Claims, credits
- ☐ Sales reporting
- ☐ Product-return information
- ☐ Warranty claims
- ☐ Web page activity
- ☐ Other:

Proactive Sources

- ☐ Interviews
- ☐ Focus groups
- ☐ Surveys
- ☐ Comment cards
- ☐ Sales visits/calls
- ☐ Direct observation
- ☐ Market research/monitoring
- ☐ Benchmarking
- ☐ Quality scorecards
- ☐ Other:

Summary: Which, How Many, How, and When

On a separate sheet, summarize your plans to gather and use reactive and proactive sources. Indicate how much data you will get, how you will get it, and when. Include, for instance, the number of interviews or surveys you plan to conduct, which customers you will contact, when you will start and end the data-collection process, and so on.

Data Points

Turning data
into information

What type of data do you have?

- Words?
- Numbers?
  - *Attribute data?* Attribute data can be counted and plotted as discrete events. It includes the count of the numbers or percentages of good or bad, right or wrong, pass or fail, yes or no.

    Example: Number of correct answers on a test, number of mistakes per typed page, percent defective product per shift.
  - *Variable data?* Variable data can be measured and plotted on a continuous scale.

    Example: Length, time, volume, weight.

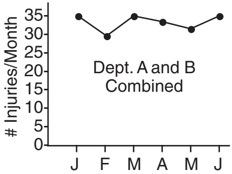
Do you need to collect data?

- If you need to know the performance of an entire population, the more economical and less time consuming method is to draw a sample from a population. With a sample, you can make inferences about, or predict, the performance of a population. Basic sampling methods are:
  - *Random.* Each and every observation or data measure has an equally likely chance of being selected. Use a random number table or random number generator to select the samples.
  - *Sequential*. Every *nth* sample is selected.
  - *Stratified.* A sample is taken from stratified data groups.

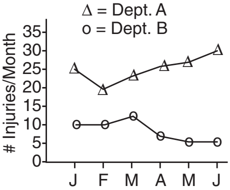
Can you categorize your data into subgroups?

- When you stratify data, you break it down into meaningful subcategories or classifications, and from this point you can focus your problem solving.

  Example: Data often comes from many sources but is treated as if coming from one. Data on minor injuries for a plant may be recorded as a single figure, but that number is actually the sum total of injuries by 1) type (cuts, burns, scrapes), 2) location (eyes, hands, feet), and 3) department (maintenance, shipping, production). Below is an example of how data has been stratified by plant department.



(Appears fairly stable over time.)



(Dept. A is running higher and may be increasing over time.)

What patterns are important in your data?

Predictable patterns or distributions can be described with statistics.

- **Measures of location**
  - *Mean* (or average). Represented by $\bar{X}$ (or X-bar), the mean is the sum of the values of the sample ($X_1, X_2, X_3 \ldots X_n$) divided by the total number (n) of sampled data.

    Example: For the sample: (3, 5, 4, 7, 5)

$$\bar{X} = \frac{(3 + 5 + 4 + 7 + 5)}{5} = 4.8$$

- *Median.* When sampled data are rank ordered, lowest to highest, the median is the middle number.

  Example: For the sample: (3, 5, 4, 7, 5) Median of (3, 4, 5, 5, 7) = 5

  When there are an even number of values, the median is the average of the middle two values.

  Example: For the sample: (2, 5, 7, 4, 5, 3) Median of (2, 3, 4, 5, 5, 7) = 4.5

- *Mode.* The most frequently occurring value(s) in a sample.

  Example: For the sample: (3, 5, 4, 7, 5) Mode = 5

- **Measures of variation**
  - *Range.* Represented by R, the range is the difference between the highest data value (X_{max}) and the lowest data value (X_{min}).

    Example: For the sample: (3, 5, 4, 7, 5) R = 7 – 3 = 4

  - *Standard Deviation.* Represented by *s*, the standard deviation of a sample measures the variation of the data around the mean. The less variation there is of the data values about the mean, $\bar{X}$, the closer *s* will be to zero (0).

Example: For the sample: (3, 5, 4, 7, 5) $\bar{X} = 4.8$

$$s = \sqrt{\frac{[(3-4.8)^2 + (5-4.8)^2 + (4-4.8)^2 + (7-4.8)^2 + (5-4.8)^2]}{5-1}}$$

$$= \sqrt{\frac{[3.24 + .04 + .64 + 4.84 + .04]}{4}}$$

$$= \sqrt{\frac{8.8}{4}}$$

$$= \sqrt{2.2}$$

$$= 1.48$$

The square of the standard deviation, s, is referred to as the *variance*. Variance is not discussed in this book.

Design of Experiments (DOE)

Testing
multiple causes

Why use it?

With most data-analysis methods, you observe what happens in a process without intervening. With a designed experiment, you change the process settings to see the effect this has on the process output. The term *design of experiments* refers to the structured way you change these settings so that you can study the effects of changing multiple settings simultaneously.

This active approach allows you to effectively and efficiently explore the relationship between multiple process variables (x's) and the output, or process performance variables (y's). This tool is most commonly used in the Analyze step of the DMAIC method as an aid in identifying and quantifying the key drivers of variation, and in the Improve step as an aid in selecting the most effective solutions from a long list of possibilities.

What does it do?

- Identifies the "vital few" sources of variation (x's)—the factors that have the biggest impact on the results
- Identifies the x's that have little effect on the results
- Quantifies the effects of the important x's, including their interactions
- Produces an equation that quantifies the relationship between the x's and the y's
- Predicts how much gain or loss will result from changes in process conditions

How do I do it?

1. **Get background information on the problem**
    - Study available data from the Define, Measure, and Analyze steps of the DMAIC method.
    - Examine internal and external literature about solutions to the problem.
    - Clarify the experimental budget and constraints.

2. **Identify responses, factors, and factor levels**
    - Select one or more measurable responses (y's).
    - Define the measurement procedure for each y.
    - Identify all the factors (x's) that might impact each y.
    - Consider all pairs of factors that might interact (i.e., act quite differently in combination than they do alone).
    - Determine the high and low experimental levels for each factor.
    - Review combinations of factor levels for potential problems.

3. **Select the design**
    - Select a design appropriate for your current level of knowledge that allows you to examine the desired number of factors.
    - Decide on the number of experimental trials, or runs, you will perform.
    - If possible, build some replication into the final design; consider how large a defect must be for a customer to detect it.
    - Randomize the order of the runs whenever possible.
    - Consider the need for blocking. If you can conduct only a certain number of the experimental runs

under a similar set of conditions (e.g., only eight samples fit into an oven, so you must bake the other eight samples separately), then you need to run a blocked experiment. *Blocking* means determining which runs belong together under the same set of conditions. You must consider such blocking arrangements when you make your subsequent analysis.

4. Collect the data

- Prepare a data-collection form that has room for all pertinent information, including written comments.
- Schedule the needed equipment, people, and materials.
- If necessary, provide training to everyone involved in doing the experiment, including those who will randomize and run the tests, take measurements, and so on.
- Label and save all samples and results if possible.
- Be present during the experiment process to monitor its performance carefully; keep a logbook of events, especially deviations from the plan.
- Review the raw data as it is collected and correct any mistakes immediately.

5. Analyze the data

- Plot the raw data in various ways.
- If the experiment includes replications, compute averages, standard deviations, and residuals for each experimental condition and plot them in various ways.
- Compute the factors' effects and interactions and plot them in various ways.
- Where useful, develop a prediction model to relate factors to responses.

- When appropriate, confirm impressions from plots with appropriate statistical analysis.

6. **Draw, verify, and report your conclusions**
   - Interpret the results of the experiment using only known information (i.e., that which is theoretical or observed).
   - Formulate and write conclusions in simple, nonstatistical language that others can understand.
   - Verify your conclusions with additional runs.
   - When appropriate, go on to the next iteration of your study.
   - Prepare a written report of the conclusions and recommendations to finish the Analyze step of the DMAIC method.

7. **Implement recommendations**
   - Continue with the Improve and Control steps of the DMAIC method.

Tip Use a Cause & Effect Diagram as an integral part of your discussion to identify and select the factors (x's) to use.

Tip The most difficult parts of this process are Step 3 (selecting the design), Step 4 (collecting the data), and Step 5 (analyzing the data). The team's Six Sigma Expert or Master Six Sigma Expert should lead these steps and explain them to the team when it is appropriate to do so.

Tip Plan on using no more than 25% of your entire experimental budget on the first set of runs. Follow-up experiments are usually necessary to get additional information or to confirm what was already learned.

Variations

Many different experimental designs fall under the heading of "design of experiments." Listed below are some common design types used in Six Sigma improvement processes.

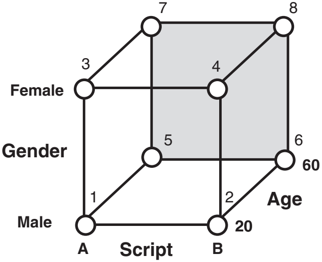
- Two-level fractional factorial screening designs: used to identify the vital few x's from many potential factors.
- Two-level full- and high-resolution fractional designs: used to help a team understand how the important factors act together to influence the response.
- Robust designs, or Taguchi designs: used to study the effect of the factors on not just the average response (y) but also on the amount of variation in the y.
- Response surface methodology: used to determine optimum settings for important factors.
- Evolutionary operation, or EVOP: used to experiment on a process while it is "on-line." If you limit the changes you make to the factor levels, all output produced might still meet customer requirements.

Sample Experiment

A team conducted an experiment to study the effects of three factors (script used, gender of caller, and age of caller) on an outbound telephone-sales process. They studied what the caller said during the call (Script A or B), whether the caller was male or female, and whether the caller had a young voice or an old voice (age = 20 or age = 60). All combinations of these factors are shown in the chart on the next page and are represented on the cube. The team then determined how many sales the callers made in a given time period (e.g., four hours of calling) and recorded the results in a table and plotted them on a cube by filling in the appropriate circle with the result (see below).

Results from the Sample Experiment

Standard Order	Script	Gender	Age	y = No. of Sales
1	A	Male	20	_____
2	B	Male	20	_____
3	A	Female	20	_____
4	B	Female	20	_____
5	A	Male	60	_____
6	B	Male	60	_____
7	A	Female	60	_____
8	B	Female	60	_____



Failure Mode and Effects Analysis (FMEA)

Anticipating
& preventing failures

Why use it?

Failure Mode and Effects Analysis (FMEA) is used to identify specific ways in which a product, process, or service might fail and to then develop countermeasures targeted at those specific failures. This will improve performance, quality, reliability, and safety. FMEA is most commonly used in the Improve step of the DMAIC method to improve the effectiveness of a proposed solution, but it is also helpful in the Recognize step for identifying improvement opportunities, and in the Measure step for determining what data to collect and where to collect it.

What does it do?

- Follows the steps of the process and identifies where problems might occur
- Scores potential problems based on their probability of occurrence, severity, and ability to be detected
- Based on the scores mentioned above, helps to determine where countermeasures are necessary to avoid problems
- Allows re-scoring of the problem after you have put countermeasures in place

How do I do it?

1. **List the process steps in the first column of a chart like the one below**

Sample FMEA Chart

Project ____________ Team ____________ Date ____________(original)
____________(revised)

Item or Process Step	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)	Occurrence	Current Controls	Detection	RPN	Recommended Action	Responsibility and Target Date	"After"→ Action Taken	Severity	Occurrence	Detection	RPN
Total Risk Priority Number =									"After" Risk Priority Number =						

2. **For each process step, brainstorm potential failure modes—ways in which the product, service, or process might fail (e.g., jams, sputters, freezes or slows up, is unreadable)**

3. **Identify the potential consequences or effects of each failure (e.g., defective product, wrong information, delays) and rate their severity**

4. **Identify causes of the effects and rate their likelihood of occurrence**

5. **Rate your ability to detect each failure mode (in the Detection column)**

6. **Multiply the three numbers (severity, occurrence, and detection) together to determine the risk of each failure mode. This is represented in the chart by a risk priority number, or RPN.**

   - RPN = severity × occurrence × detection

7. **Identify ways to reduce or eliminate risk associated with high RPNs**

8. **Re-score those failures after you put countermeasures in place**

Tip There might be multiple failures for each step and multiple effects for each failure. Score each separately.

Tip Develop your own scales for severity, occurrence, and detection or use the sample scales shown on the next page.

Sample Severity, Occurrence, & Detection Scales

Severity = likely impact of the failure

	Rating	Criteria: A failure could . . .
Bad	10	Injure a customer or employee
	9	Be illegal
	8	Render the product or service unfit for use
	7	Cause extreme customer dissatisfaction
	6	Result in partial malfunction
	5	Cause a loss of performance likely to result in a complaint
	4	Cause minor performance loss
	3	Cause a minor nuisance; can be overcome with no loss
	2	Be unnoticed; minor effect on performance
Good	1	Be unnoticed and not affect the performance

Occurrence = how often the cause will occur

	Rating	Time Period	Probability
Bad	10	More than once per day	> 30%
	9	Once every 3–4 days	< 30%
	8	Once per week	< 5%
	7	Once per month	< 1%
	6	Once every 3 months	< .03%
	5	Once every 6 months	< 1 per 10,000
	4	Once per year	< 6 per 100,000
	3	Once every 1–3 years	< 6 per million
	2	Once every 3–6 years	< 3 per 10 million
Good	1	Once every 6–100 years	< 2 per billion

Detection = how likely we are to know if the cause has occurred

	Rating	Definition
Bad	10	Defect caused by failure is not detectable
	9	Occasional units are checked for defects
	8	Units are systematically sampled and inspected
	7	All units are manually inspected
	6	Manual inspection with mistake-proofing modifications
	5	Process is monitored via statistical process control (SPC) and manually inspected
	4	SPC used, with an immediate reaction to out-of-control conditions
	3	SPC as above, with 100% inspection surrounding out-of-control conditions
	2	All units are automatically inspected
Good	1	Defect is obvious and can be kept from affecting customer

Variations

Error Mode and Effects Analysis (EMEA) is sometimes used to track processes in which the primary failures are human errors. With EMEA, errors, rather than failures, are tracked and scored.

Flowchart

Picturing the process

Why use it?

To allow a team to identify the actual flow or sequence of events in a process that any product or service follows. Flowcharts can be applied to anything from the travels of an invoice or the flow of materials, to the steps in making a sale or servicing a product.

What does it do?

- Shows unexpected complexity, problem areas, redundancy, unnecessary loops, and where simplification and standardization may be possible
- Compares and contrasts the actual versus the ideal flow of a process to identify improvement opportunities
- Allows a team to come to agreement on the steps of the process and to examine which activities may impact the process performance
- Identifies locations where additional data can be collected and investigated
- Serves as a training aid to understand the complete process

How do I do it?

1. **Determine the frame or boundaries of the process**
   - Clearly define where the process under study starts (input) and ends (final output).
   - Team members should agree to the level of detail they must show on the Flowchart to clearly understand the process and identify problem areas.

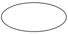
- The Flowchart can be a simple macro-flowchart showing only sufficient information to understand the general process flow, or it might be detailed to show every finite action and decision point. The team might start out with a macro-flowchart and then add in detail later or only where it is needed.

2. **Determine the steps in the process**
   - Brainstorm a list of all major activities, inputs, outputs, and decisions on a flipchart sheet from the beginning of the process to the end.

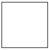
3. **Sequence the steps**
   - Arrange the steps in the order they are carried out. Use Post-it® Notes so you can move them around. Don't draw in the arrows yet.

   Tip Unless you are flowcharting a new process, sequence what *is*, not what *should be* or the ideal. This may be difficult at first but is necessary to see where the probable causes of the problems are in the process.

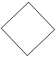
4. **Draw the Flowchart using the appropriate symbols**



An oval is used to show the materials, information, or action (inputs) to start the process or to show the results at the end (output) of the process.



A box or rectangle is used to show a task or activity performed in the process. Although multiple arrows may come into each box, usually only one output or arrow leaves each activity box.



A diamond shows those points in the process where a yes/no question is being asked or a decision is required.

A circle with either a letter or a number identifies a break in the Flowchart and is continued elsewhere on the same page or another page.

→ Arrows show the direction or flow of the process.

- Keep the Flowchart simple using the basic symbols listed above. As your experience grows, use other, more graphic symbols to represent the steps. Other symbols sometimes used include:
  - A half or torn sheet of paper for a report completed and/or filed.
  - A can or computer tape wheel for data entry into a computer database.
  - A large "D" or half circle to identify places in the process where there is a delay or wait for further action.
- Be consistent in the level of detail shown.
  - A macro-level flowchart will show key action steps but no decision boxes.
  - An intermediate-level flowchart will show action and decision points.
  - A micro-level flowchart will show minute detail.
- Label each process step using words that are understandable to everyone.
- Add arrows to show the direction of the flow of steps in the process. Although it is not a rule, if you show all "yes" choices branching down and "no" choices branching to the left, it is easier to

follow the process. Preferences and space will later dictate direction.

- Don't forget to identify your work. Include the title of your process, the date the diagram was made, and the names of the team members.

5. Test the Flowchart for completeness

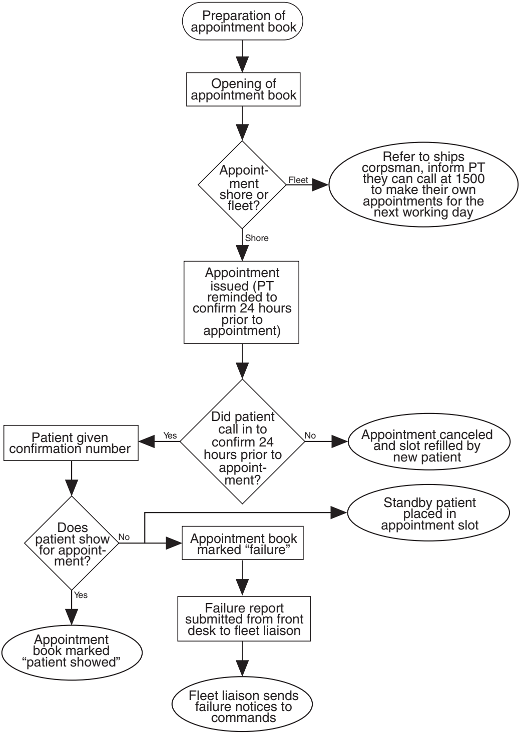
- Are the symbols used correctly?
- Are the process steps (inputs, outputs, actions, decisions, waits/delays) identified clearly?
- Make sure every feedback loop is closed, i.e., every path takes you either back to or ahead to another step.
- Check that every continuation point has a corresponding point elsewhere in the Flowchart or on another page of the Flowchart.
- There is usually only one output arrow out of an activity box. If there is more than one arrow, you may need a decision diamond.
- Validate the Flowchart with people who are not on the team and who carry out the process actions. Highlight additions or deletions they recommend. Bring these back to the team to discuss and incorporate into the final Flowchart.

6. Finalize the Flowchart

- Is this process being run the way it should be?
- Are people following the process as charted?
- Are there obvious complexities or redundancies that can be reduced or eliminated?
- How different is the current process from an ideal one? Draw an ideal Flowchart. Compare the two (current versus ideal) to identify discrepancies and opportunities for improvements.

Flowchart

Proposed Patient Appointment Procedure



Information provided courtesy of U.S. Navy, Naval Dental Center, San Diego

Variations

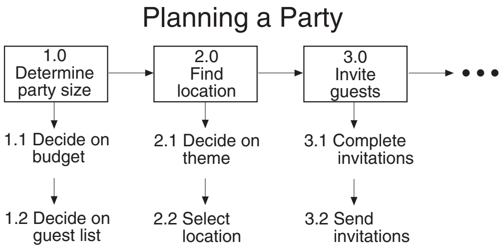
The type of Flowchart just described is sometimes referred to as a "detailed" flowchart because it includes, in detail, the inputs, activities, decision points, and outputs of any process. Four other forms, described below, are also useful.

Macro-Flowchart

Refer to the third bulleted item in Step 1 of this section for a description. For a graphic example, see page 119 of *The Memory Jogger™ II*.

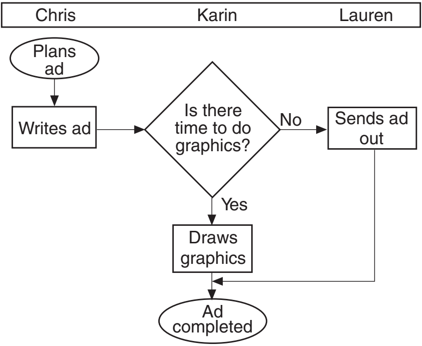
Top-Down Flowchart

This chart is a picture of the major steps in a work process. It minimizes the detail to focus only on those steps essential to the process. It usually does not include inspection, rework, and other steps that result in quality problems. Teams sometimes study the top-down flowchart to look for ways to simplify or reduce the number of steps to make the process more efficient and effective.



Deployment Flowchart

This chart shows the people or departments responsible and the flow of the process steps or tasks they are assigned. It is useful to clarify roles and track accountability as well as to indicate dependencies in the sequence of events.

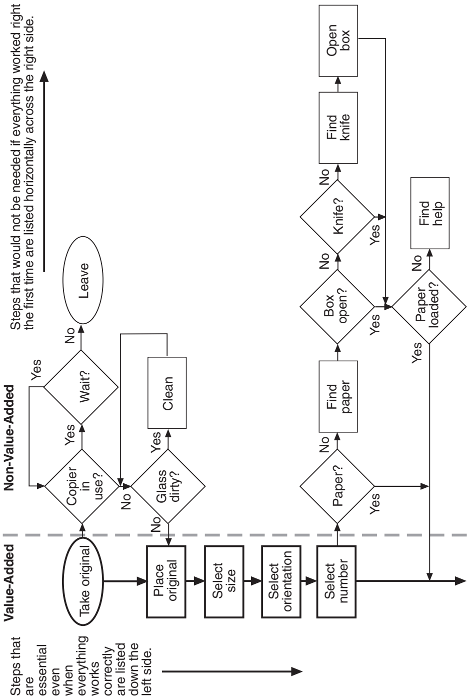


Opportunity Flowchart

This type of chart helps you improve a process by differentiating its value-added steps from its non-value-added steps. *Value-added steps* are those that are essential for producing the product or service and are needed even if the process were to run perfectly every time. *Non-value-added steps* are those that are added to a process because defects, errors, and omissions occur or because of worry that they might occur.

Remember these tips when constructing an Opportunity Flowchart: Divide a page into two sections. The value-added section should be smaller than the non-value-added section. Time flows down the page. Join two value-added steps with an arrow only if there are no non-value-added steps in between.

A Sample Opportunity Flowchart



Workflow Flowchart

This type of chart is used to show the flow of people, materials, paperwork, etc., within a work setting. When redundancies, duplications, and unnecessary complexities are identified in a path, people can take action to reduce or eliminate these problems.

Focused Problem Statement

Narrowing the problem definition

Why use it?

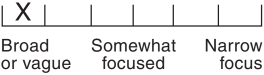
To narrow the focus of a problem so that you can use your time and resources most effectively in finding a solution.

What does it do?

- Describes specifically what occurs, when or under what circumstances it occurs, and/or who is involved
- Prevents a team from getting bogged down trying to do too much at once
- Alleviates the difficulties of getting beyond general issues, which are harder to tackle than specific ones
- Keeps the team motivated and focused

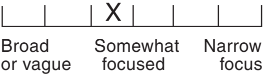
Narrowing a Problem Statement

Poor service at the
Royal Treatment Hotel.



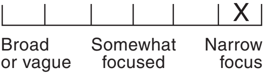
What: *Poor service*

Late room service at the
Royal Treatment Hotel.



What: *Poor service*
What type of service: *Room service*
What about the service: *It is late*

Late room service
between 6 a.m. and 8 a.m.
on weekdays at the
Royal Treatment Hotel.



What: *Poor service*
What type of service: *Room service*
What about the service: *It is late*
When is this problem the greatest:
Between 6 a.m. and 8 a.m. on weekdays

How do I do it?

1. **Review the problem statement on your charter**

2. **Review the data from the Measure step of the DMAIC method to get clues about the specifics (i.e., who, what, when, where, which) of the problem you are addressing**

3. **Complete a worksheet like the one on the next page using the questions provided to develop a Focused Problem Statement**

Creating a Focused Problem Statement

Focus your problem by asking who, what, when, where, and which.

What is the nature of the problem?

- What happens?
- What type of problem is it?
- What do we know about it?

Where does the problem occur?

- Physical location
- Step in the process

When does the problem occur?

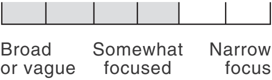
- Day, time of day, shift, month, season, annual cycle
- When doesn't it occur?
- When is the problem greatest?

Who is involved?

- Which customers?
- Which suppliers?
- Who else is involved?

Use the questions on the left to help you write a Focused Problem Statement.

Put an X where you think your problem statement falls on the scale.



If your problem statement falls in the shaded area, what data or other information can you collect to help make your problem statement more focused?

Tip If you have no answers or vague answers to the questions on the worksheet, you might need to do more work in the Measure step of the DMAIC method before proceeding with the Analyze step.

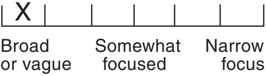
Tip There are no rules that tell you when a problem is focused enough. Trying to develop a Focused Problem Statement is a balancing act. You want to have enough focus so that it is easy to identify causes and take effective action, but you don't want to spend so much time, effort, and money on this step that you never get around to taking action! At some point, therefore, you have to decide whether the cost of getting more data and more focus is worth the investment.

Sample Focused Problem Statements

Situation	**Broad, vague →**	**Somewhat focused →**	**Narrow focus**
Product development	*Missed deadlines*	*New products routinely miss target launch dates*	*New CD-ROM products routinely miss target launch dates by three months*
Accounts receivable	*Late payments*	*Late payments from Service A customers*	*Late payments from international customers of Service A*
Injuries	*Muscle strains*	*High number of muscle strains among warehouse personnel*	*High number of back-muscle strains among material handlers*

A Comparison of Problem Statements

Takes too long to close the books at the end of the month



What: *Closing the books*

Does not include:

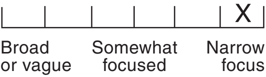
Which departments have problems

When the problem started

Whether the problem happens all the time or comes and goes

What types of financial records have the biggest delays

Increase in the number of open inner packs of Fiber Flakes cereal from the #3 sealing machine during the last three days



What product is involved: *Fiber Flakes cereal*

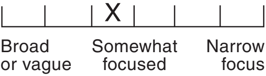
What problem occurs: *Increase in open packs*

Which packs: *Inner packs*

Where does problem occur: *Sealing machine #3*

When did problem occur: *The last three days*

Inaccurate hospital bills for surgery patients at City Hospital



What: *Inaccurate bills*

Which patients: *Surgery patients*

Where: *City Hospital*

Does not include:

What types of inaccuracies?

What kinds of surgeries?

When did the problem start?

Histogram

Process centering, spread, and shape

Why use it?

To summarize data from a process that has been collected over a period of time, and graphically present its frequency distribution in bar form.

What does it do?

- Displays large amounts of data that are difficult to interpret in tabular form
- Shows the relative frequency of occurrence of the various data values
- Reveals the centering, variation, and shape of the data
- Illustrates quickly the underlying distribution of the data
- Provides useful information for predicting future performance of the process
- Helps to indicate if there has been a change in the process
- Helps answer the question "Is the process capable of meeting my customer requirements?"

How do I do it?

1. Decide on the process measure

- The data should be variable data, i.e., measured on a continuous scale. For example: temperature, time, dimensions, weight, speed.

2. Gather data

- Collect at least 50 to 100 data points if you plan on looking for patterns and calculating the distribution's centering (mean), spread (variation), and shape. You might also consider collecting data for a specified period of time: hour, shift, day, week, etc.
- Use historical data to find patterns or to use as a baseline measure of past performance.

3. Prepare a frequency table from the data

a) Count the number of data points, n, in the sample.

9.9	9.3	10.2	9.4	10.1	9.6	9.9	10.1	9.8
9.8	9.8	10.1	9.9	9.7	9.8	9.9	10.0	9.6
9.7	9.4	9.6	10.0	9.8	9.9	10.1	10.4	10.0
10.2	10.1	9.8	10.1	10.3	10.0	10.2	9.8	10.7
9.9	10.7	9.3	10.3	9.9	9.8	10.3	9.5	9.9
9.3	10.2	9.2	9.9	9.7	9.9	9.8	9.5	9.4
9.0	9.5	9.7	9.7	9.8	9.8	9.3	9.6	9.7
10.0	9.7	9.4	9.8	9.4	9.6	10.0	10.3	9.8
9.5	9.7	10.6	9.5	10.1	10.0	9.8	10.1	9.6
9.6	9.4	10.1	9.5	10.1	10.2	9.8	9.5	9.3
10.3	9.6	9.7	9.7	10.1	9.8	9.7	10.0	10.0
9.5	9.5	9.8	9.9	9.2	10.0	10.0	9.7	9.7
9.9	10.4	9.3	9.6	10.2	9.7	9.7	9.7	10.7
9.9	10.2	9.8	9.3	9.6	9.5	9.6	10.7	

In this example, there are 125 data points, $n = 125$.

b) Determine the range, R, for the entire sample.

The range is the smallest value in the set of data subtracted from the largest value. For our example:

$$R = X_{max} - X_{min} = 10.7 - 9.0 = 1.7$$

c) Determine the number of class intervals, k, needed.

- Method 1: Take the square root of the total number of data points and round to the nearest whole number.

$$k = \sqrt{125} = 11.18 = 11 \text{ intervals}$$

- Method 2: Use the table below to provide a guideline for dividing your sample into a reasonable number of classes.

Number of Data Points	Number of Classes (k)
Under 50	5 – 7
50 – 100	6 – 10
100 – 250	7 – 12
Over 250	10 – 20

For our example, 125 data points would be divided into 7–12 class intervals.

Tip These two methods are general rules of thumb for determining class intervals. In both methods, consider using $k = 10$ class intervals for ease of "mental" calculation.

Tip The number of intervals can influence the pattern of the sample. Too few intervals will produce a tight, high pattern. Too many intervals will produce a spread-out, flat pattern.

d) Determine the class width, H.

- The formula for this is:

$$H = \frac{R}{k} = \frac{1.7}{10} = .17$$

- Round your number to the nearest value with the same decimal numbers as the original sample. In our example, we would round up to .20. It is useful to have intervals defined to one more decimal place than the data collected.

e) Determine the class boundaries, or end points.

- Use the smallest individual measurement in the sample, or round to the next appropriate lowest round number. This will be the lower end point for the *first* class interval. In our example this would be 9.0.
- Add the class width, H, to the lower end point. This will be the lower end point for the *next* class interval. For our example:

  $$9.0 + H = 9.0 + .20 = 9.20$$

  Thus, the first class interval would be 9.00 and everything up to, *but not including*, 9.20; that is, 9.00 through 9.19. The second class interval would begin at 9.20 and be everything up to, but not including, 9.40.

Tip Each class interval must be *mutually exclusive*; that is, every data point will fit into *one and only one* class interval.

- Consecutively add the class width to the lowest class boundary until the k class intervals and/or the range of all the numbers are obtained.

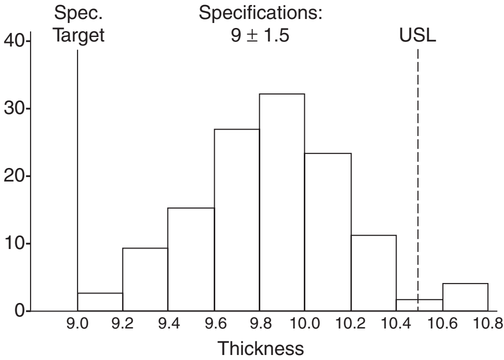
f) Construct the frequency table based on the values you computed in item "e."

A frequency table based on the data from our example is shown below.

Class #	Class Boundaries	Mid-Point	Frequency	Total
1	9.00-9.19	9.1	|	1
2	9.20-9.39	9.3	𝍸 ||||	9
3	9.40-9.59	9.5	𝍸 𝍸 𝍸 |	16
4	9.60-9.79	9.7	𝍸 𝍸 𝍸 𝍸 𝍸 ||	27
5	9.80-9.99	9.9	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 |	31
6	10.00-10.19	10.1	𝍸 𝍸 𝍸 𝍸 ||	22
7	10.20-10.39	10.3	𝍸 𝍸 ||	12
8	10.40-10.59	10.5	||	2
9	10.60-10.79	10.7	𝍸	5
10	10.80-10.99	10.9		0

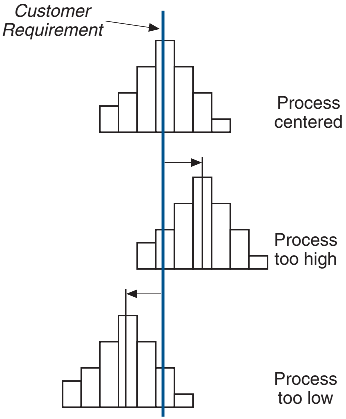
4. **Draw a Histogram from the frequency table**

- On the vertical line (y axis), draw the frequency (count) scale to cover class interval with the highest frequency count.
- On the horizontal line (x axis), draw the scale related to the variable you are measuring.
- For each class interval, draw a bar with the height equal to the frequency tally of that class.

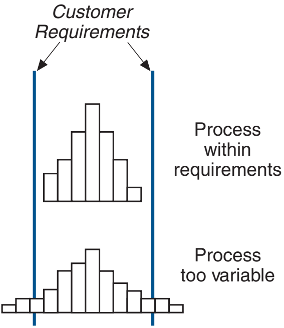


5. Interpret the Histogram

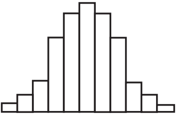
a) *Centering.* Where is the distribution centered? Is the process running too high? Too low?

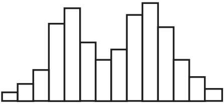


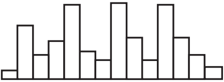
b) *Variation.* What is the variation or spread of the data? Is it too variable?

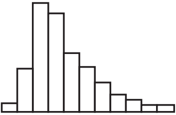


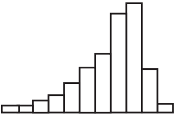
c) *Shape*. What is the shape? Does it look like a normal, bell-shaped distribution? Is it positively or negatively skewed; that is, more data values to the left or to the right? Are there twin (bi-modal) or multiple peaks?


Normal Distribution


Bi-Modal Distribution


Multi-Modal Distribution


Positively Skewed

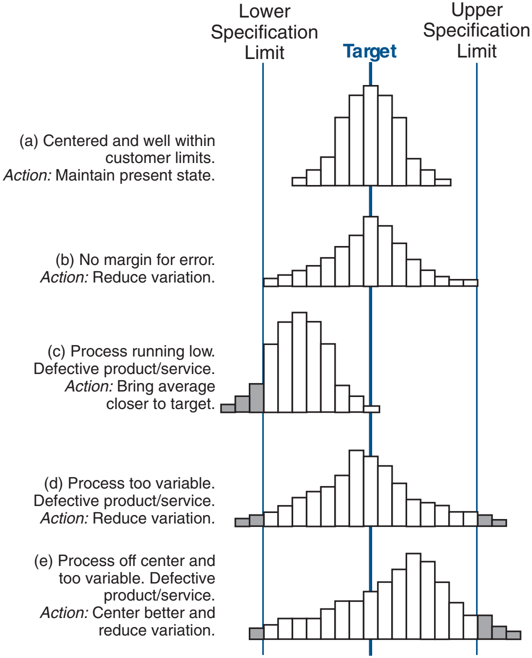

Negatively Skewed

Tip Some processes are naturally skewed; don't expect every distribution to follow a bell-shaped curve.

Tip Always look for twin or multiple peaks indicating that the data is coming from two or more different sources, e.g., shifts, machines, people, suppliers. If this is evident, stratify the data.

d) *Process Capability.* Compare the results of your Histogram to your customer requirements or specifications. Is your process capable of meeting the requirements, i.e., is the Histogram centered on the target and within the specification limits?

Centering and Spread Compared to Customer Target and Limits



Tip Get suspicious of the accuracy of the data if the Histogram suddenly stops at one point (such as a specification limit) without some previous decline in the data. It could indicate that defective product is being sorted out and is not included in the sample.

Tip The Histogram is related to the Control Chart. Like a Control Chart, a normally distributed Histogram will have almost all its values within ±3 standard deviations of the mean. See page 132 of *The Memory Jogger™ II* for an illustration of this.

Variations

Stem & Leaf Plot

This plot is a cross between a frequency distribution and a Histogram. It exhibits the shape of a Histogram, but preserves the original data values—one of its key benefits! Data is easily recorded by writing the trailing digits in the appropriate row of leading digits.

	Data as collected		*Data rank-ordered*
.05	7	.05	7
.06	4	.06	4
.07	5 7	.07	5 7
.08	1 9 3 9	.08	1 3 9 9
.09	7 4 8 2 6 9 4	.09	2 4 4 6 7 8 9
.10	7 2 0 4 3 5 9	.10	0 2 3 4 5 7 9
.11	3 1 9 3 7 3 8 6 6	.11	1 3 3 3 6 6 7 8 9
.12	2 4 8 0 8 9 0 5	.12	0 0 2 4 5 8 8 9
.13	2 5 2 7 7 6	.13	2 2 5 6 7 7
.14	0 3 6 9	.14	0 3 6 9
.15	4 7	.15	4 7
.16	4	.16	4

In this example, the smallest value is .057, and the largest value is .164. Using such a plot, it is easy to find the median and range of the data.

- Median = middle data value (or average of the two middle values) when the data is ranked from smallest to largest.

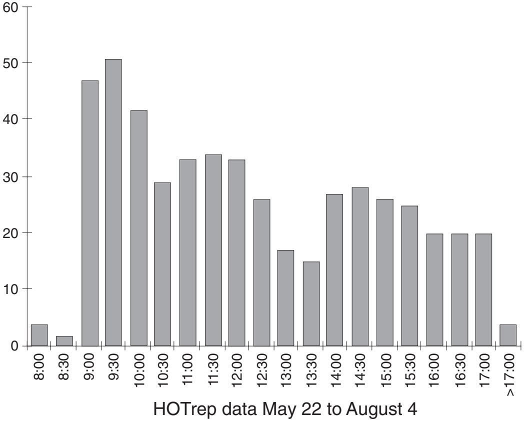
For this example, there are 52 data points. Therefore, the average of the 26th and 27th value will give the median value.

Median = (.113 + .116)/2 = .1145

- Range = Highest value – lowest value = .164 – .057 = .107

Histogram

Time Distribution of Calls

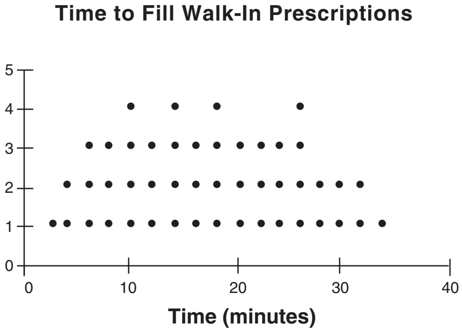


Information provided courtesy of SmithKline Beecham

Note: The Histogram identified three peak calling periods at the beginning of the workday and before and after the traditional lunch hour. This can help the HOTreps synchronize staffing with their customer needs.

Dot Plot

Like a Histogram, a Dot Plot illustrates the frequency of occurrences, except dots are used to represent frequency on the chart instead of bars.

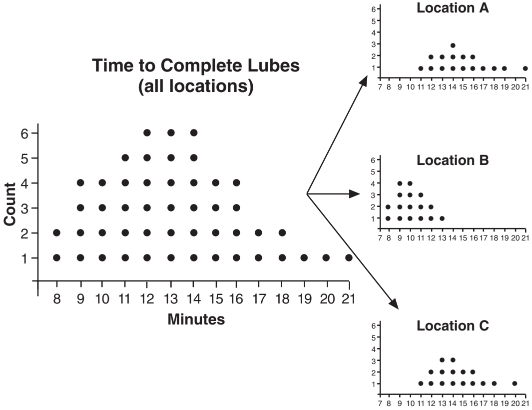


Stratifying Frequency Diagrams

As described in the Data Collection section, stratification can provide useful insight into what is actually happening in a process. When displaying stratified data, you should code the data points to visually separate the various data groups. You can use the following methods to code your data:

- Different labels, colors, or symbols
- Different plots side by side

A Sample Stratified Frequency Diagram

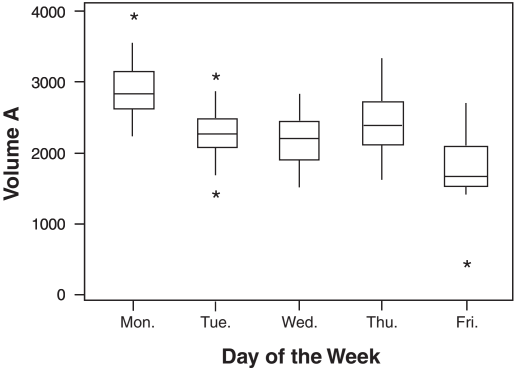


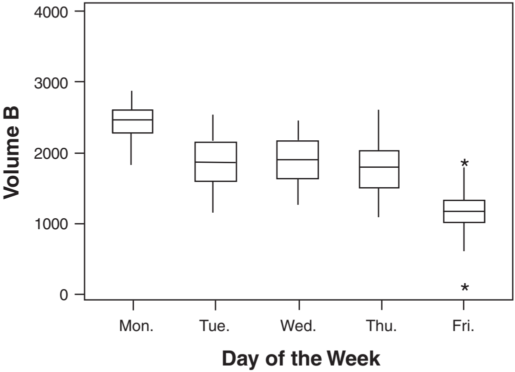
Box Plot

A Box Plot (also known as a Box and Whisker Plot) is particularly helpful for showing the distribution of data. It shows similar information as the Dot Plot and has a few additional features. In this example, a team was looking at call volumes by day of the week. This data is shown on the next page in the form of a Box Plot.

The outline of the box on the Box Plot indicates the middle 50% of the data (the middle two quartiles). The line inside the box represents the median. The lines extending on either side of the box, called whiskers, represent an upper limit and a lower limit. These limits are based on one and one-half times the length of the box added to either side of the box (if there are values that extreme) or the highest or lowest value. The asterisk represents any values that lie beyond the limits.

Sample Box Plots





Hypothesis Testing

Checking for differences

Why use it?

Hypothesis testing is used to help determine if the variation between groups of data is due to true differences between the groups or is the result of *common-cause variation*, which is the natural variation in a process. This tool is most commonly used in the Analyze step of the DMAIC method to determine if different levels of a discrete process setting (x) result in significant differences in the output (y). An example would be "Do different regions of the country have different defect levels?" This tool is also used in the Improve step of the DMAIC method to prove a statistically significant difference in "before" and "after" data.

What does it do?

- Identifies whether a particular discrete x has an effect on the y
- Checks for the statistical significance of differences. In other words, it helps determine if the difference observed between groups is bigger than what you would expect from common-cause variation alone.
- Gives a p-value, which is the probability that a difference you observe is as big as it is only because of common-cause variation
- Can be used to compare two or more groups of data, such as "before" and "after" data

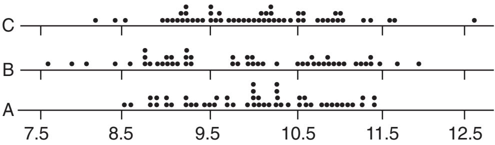
How do I do it?

1. Collect and plot the data

- You might want to make stratified histograms for the different data groups so you can get a feel for the data. Here, data collected on time to close a loan is plotted for three different loan types (A, B, and C).

  Here the hypothesis being tested is that the three different types of loans take the same amount of time to close. The hypothesis test will tell us the likelihood of that being true, even though the data plot is inconclusive.

A Hypothesis-Testing Data Plot

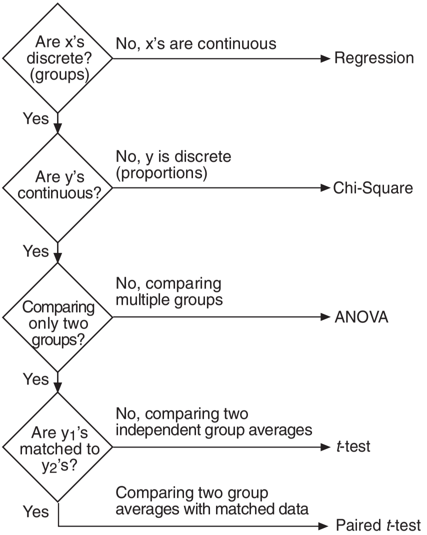


2. Select the appropriate test

- The type of hypothesis test you use depends on the type of data you have. Use hypothesis tests when the x is discrete. (See the table at left on the next page. Use the flowchart on the right as a guide for selecting the appropriate type of hypothesis test to use.)

  Since the y in this example (time to close) is continuous and the x (loan type) is discrete, Analysis of Variance is the appropriate type of test to select.

Which Hypothesis Test to Use?



y (output)	**x (input)** Discrete ("groups")	**x (input)** Continuous
Continuous	*t*-test Paired *t*-test ANOVA	Regression
Discrete (proportions)	Chi-Square	Logistic Regression

3. Analyze the data

- Hypothesis tests compare observed differences between groups.
- Hypothesis tests give a p-value. This value equals the probability of obtaining the observed difference given that the "true" difference is zero.
- A p-value can range from 0.0 to 1.0 (i.e., from a 0% chance to a 100% chance).
- Usually, a p-value of less than .05 indicates that a difference is significant. When you get a p-value of less than .05, then conclude there is little chance that the true difference is zero.
- When a difference is significant, you can conclude that the data groups are different. You can then investigate x as a driver of y or conclude there is a difference in the "before" and "after" data.

For this example, the averages of the three groups are as follows: A = 10.02, B = 9.86, and C = 10.03. The hypothesis test gives a p-value of 0.56—larger than 0.05, which indicates that the differences in the group averages are small. This means that there is not enough evidence to conclude that the different loan types have different cycle times.

Tip Hypothesis tests often require you to gather a lot of data to observe a significant difference. Work with your Six Sigma Expert or Master Six Sigma Expert to determine the power of your test and to detect the size difference you are looking for. You might need to collect additional data to see the difference you desire.

Tip Hypothesis tests are so named because they start with what is called a *null hypothesis* and set out to prove or disprove it. The null hypothesis states that there is no difference between the groups. This null hypothesis is assumed to be true until it is disproven with data. If the result of the test proves to be significant ($p < .05$), the null hypothesis is declared to be untrue.

Tip When performing Analysis of Variance (ANOVA) testing, you should also perform an additional hypothesis test for equal variance in the subgroups. The ANOVA assumes equal variances. Your Six Sigma Expert or Master Six Sigma Expert can help you draw conclusions if this assumption is not met.

Variations

Many statistical procedures have built-in hypothesis tests. For example, in regression analysis (see page 214 for details), p-values are given on a slope. These values come from a test of the null hypothesis that the slope is zero (i.e., there is no difference in slope).

Interrelationship Digraph (ID)

Looking for drivers & outcomes

Why use it?

To allow a team to systematically identify, analyze, and classify the cause-and-effect relationships that exist among all critical issues so that key drivers or outcomes can become the heart of an effective solution.

What does it do?

- Encourages team members to think in multiple directions rather than linearly
- Explores the cause-and-effect relationships among all the issues, including the most controversial
- Allows the key issues to emerge naturally rather than allowing the issues to be forced by a dominant or powerful team member
- Systematically surfaces the basic assumptions and reasons for disagreements among team members
- Allows a team to identify root cause(s) even when credible data doesn't exist

How do I do it?

1. Agree on the issue/problem statement

What are the issues related
to reducing litter?

- If using an original statement (i.e., it didn't come from a previous tool or discussion), create a complete sentence that is clearly understood and agreed on by team members.

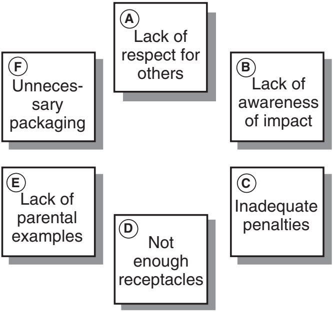
- If using input from other tools, such as an Affinity Diagram, make sure that the goal under discussion is still the same and clearly understood.

2. Assemble the right team

- The ID requires more intimate knowledge of the subject under discussion than is needed for the Affinity. This is important if the final cause-and-effect patterns are to be credible.
- The ideal team size is generally 4–6 people. However, this number can be increased as long as the issues are still visible and the meeting is well facilitated to encourage participation and maintain focus.

3. Lay out all of the ideas/issue cards that have either been brought from other tools or brainstormed

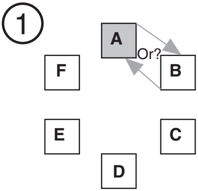
- Arrange 5–25 cards or notes in a large circular pattern, leaving as much space as possible for drawing arrows. Use large, bold printing, including a large number or letter on each idea for quick reference later in the process.



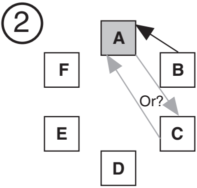
4. Look for cause/influence relationships among all of the ideas and draw relationship arrows

- Choose any of the ideas as a starting point. If all of the ideas are numbered or lettered, work through them in sequence.
- An outgoing arrow from an idea indicates that it is the stronger cause or influence.

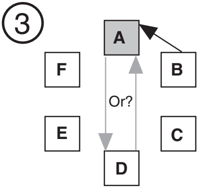
Ask of each combination:
1) Is there a cause/influence relationship?
2) If yes, which direction of cause/influence is stronger?



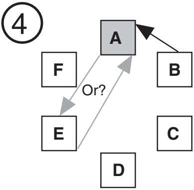
Decision: "B" causes or influences "A"



Decision:
No relationship



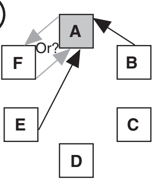
Decision:
No relationship



Decision: "E" causes or influences "A"

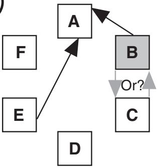
Continued next page

⑤



Decision:
No relationship.
"A" is completed.

⑥



Decision: “B” causes or
influences “C.”
Now begin with “B” and repeat the questions for all remaining combinations.

Tip Draw only one-way relationship arrows in the direction of the stronger cause or influence. Make a decision on the stronger direction. ***Do not draw two-headed arrows.***

5. Review and revise the first-round ID

- Get additional input from people who are not on the team to confirm or modify the team’s work. Either bring the paper version to others or reproduce it using available software. Use a different-size print or a color marker to make additions or deletions.

6. Tally the number of outgoing and incoming arrows and select key items for further planning

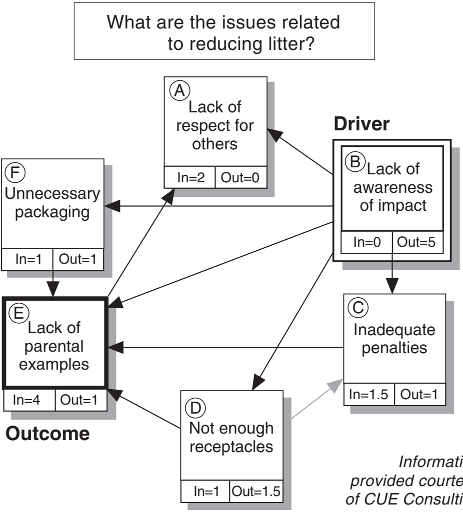
- Record and clearly mark next to each issue the number of arrows going in and out of it.
- Find the item(s) with the highest number of *outgoing arrows* and the item(s) with the highest number of *incoming arrows*.
- *Outgoing arrows*. A high number of outgoing arrows indicates an item that is a root cause or driver. This is *generally* the issue that teams tackle first.

- *Incoming arrows*. A high number of incoming arrows indicates an item that is a key outcome. This can become a focus for planning either as a meaningful measure of overall success or as a redefinition of the original issue under discussion.

Tip Use common sense when you select the most critical issues to focus on. Issues with very close tallies must be reviewed carefully, but in the end it is a judgment call, not science.

7. Draw the final ID

- Identify visually both the *key drivers* (greatest number of outgoing arrows) and the *key outcomes* (greatest number of incoming arrows). Typical methods are double boxes or bold boxes.



Information provided courtesy of CUE Consulting

Variations

When it is necessary to create a more orderly display of all of the relationships, a matrix format is very effective. The vertical (up) arrow is a driving cause, and the horizontal (side) arrow is an effect. The example below has added symbols indicating the strength of the relationships.

The "total" column is the sum of all of the "relationship strengths" in each row. This shows that you are working on those items that have the strongest effect on the greatest number of issues.

ID – Matrix Format

	Logistic Support	Customer Satisfaction	Education & Training	Personnel Incentives	Leadership	Cause /Driver ↑	Result/ Rider ↲	Total
Logistic Support	■	⊙ ↑	○ ↑	△ ↑	○ ↲	3	1	16
Customer Satisfaction	⊙ ↲	■	○ ↲	⊙ ↲	○ ↲	0	4	24
Education & Training	○ ↲	○ ↑	■	○ ↑	⊙ ↲	2	2	18
Personnel Incentives	△ ↲	⊙ ↑	○ ↲	■	⊙ ↲	1	3	22
Leadership	○ ↑	○ ↑	⊙ ↑	⊙ ↑	■	4	0	24

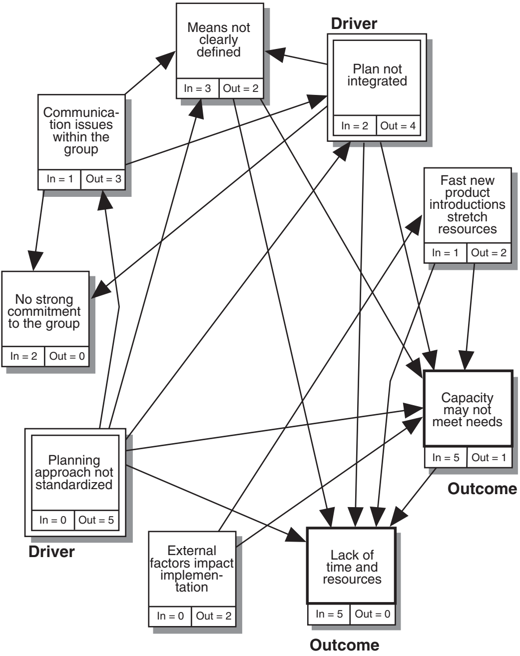
Relationship Strength

⊙ = 9 Significant
○ = 3 Medium
△ = 1 Weak

Information provided courtesy of U.S. Air Force, Air Combat Command

Interrelationship Digraph

Issues Surrounding Implementation of the Business Plan



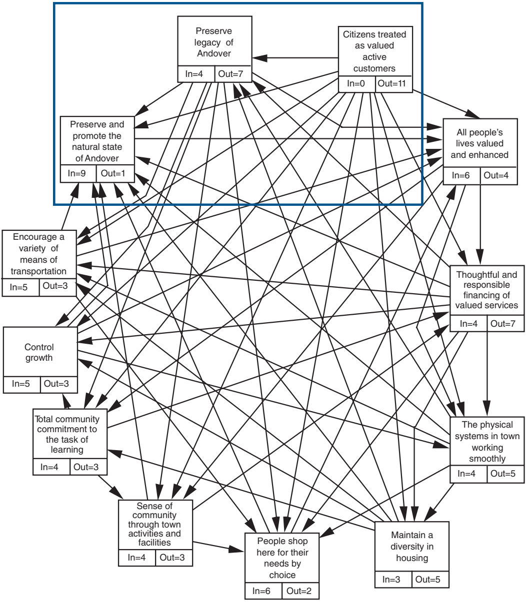
Information provided courtesy of Goodyear

Note: The "drivers" from this ID will be used as the goal in the Tree example shown at the end of the Tree Diagram/PDPC section.

Interrelationship Digraph

A Vision of Andover in the 21st Century

See next page for close-up

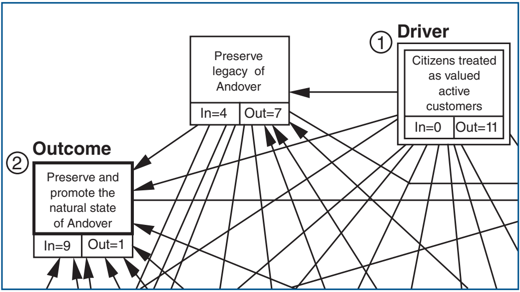


Information provided courtesy of Town of Andover, MA

Interrelationship Digraph

A Vision of Andover in the 21st Century

Close-up



Information provided courtesy of Town of Andover, MA

① This is the driver. If the focus on the citizen as a customer becomes the core of the town's vision, then everything else will be advanced.

② This is the primary outcome. It puts the preservation of nature in the town as a key indicator of the vision working.

Involvement Matrix

Involving people
in your project

Why use it?

To determine the appropriate level of involvement for different groups of stakeholders.

What does it do?

- Identifies the many people involved in making a change happen
- Describes the level of involvement required of each stakeholder group. Not everyone needs to be completely involved at every stage.
- Maps the involvement required for the major tasks in the project

The matrix on the next page will help you think about who should be involved in the different steps needed to make change a reality, as well as what level of involvement is appropriate for them.

A Sample Involvement Matrix

Task	Which groups or individuals should be:			
	Responsible for	Involved in	Consulted with regarding	Informed about
Identifying solutions				
Selecting solutions				
Planning the implementation				
Handling potential problems				
Implementing the solution				
Monitoring results				

Tip Developing, implementing, and monitoring solutions are most often group tasks. People involved in implementation or monitoring will have more commitment to a solution if they are also involved in its development.

Kano Model

Categorizing customer needs

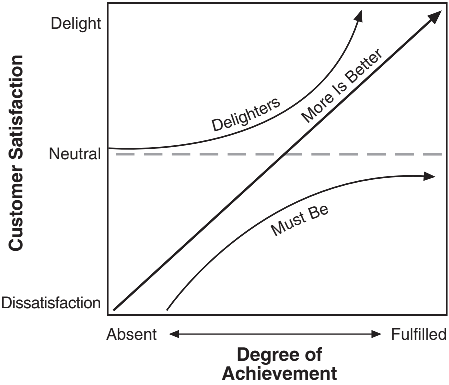
Why use it?

To identify and prioritize the full range of your customers' needs.

What does it do?

- Helps to describe which needs, if fulfilled, contribute to customer dissatisfaction, neutrality, or delight
- Identifies the "Must Be" needs, which are those that the customer expects. If they are unfulfilled, the customer is dissatisfied; however, even if they are completely fulfilled, the customer is not particularly satisfied. An example of a Must Be need is airline safety.
- Identifies the "More Is Better" needs, which are those that have a linear effect on customer satisfaction: The more these needs are met, the more satisfied customers are. An example is inexpensive airline tickets.
- Identifies "Delighter" needs, which are those that do not cause dissatisfaction when not present but satisfy the customer when they are. An example is serving hot chocolate chip cookies during an airline flight.
- Assists in the prioritization of needs—for example, Must Be needs are generally taken for granted unless they are absent. Take care of these needs first.

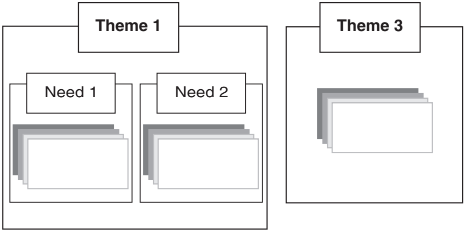
The Kano Model



How do I do it?

1. **Gather sorted customer needs from the Customer-Data Affinity Diagram. (See the CTQ Tree section for details.)**

Customer-Data Affinity Diagram



2. **Review the themes from the Affinity Diagram and sort them into the three categories in the Kano Model (Must Be, More Is Better, and Delighters)**

3. **If there are very few or no needs listed in one of the categories, collect additional customer data**

   Tip Customers generally cannot articulate what their basic expectations are or what would delight them. Therefore, when you prioritize customer needs based on what they say is important, you must remember that generally they will identify only More Is Better characteristics. You must use other means—such as direct observation of customer use—to identify and set priorities for Must Be characteristics and Delighters.

4. **After you have collected additional data, return to the Kano categories and complete the sorting of customer needs**

5. **Prioritize the customer needs you will use when you develop CTQs (see the CTQ Tree section for details)**

   Tip First work on any Must Be characteristics that, if absent, would create customer dissatisfaction. Consider the importance of More Is Better characteristics to provide steady and strong increases in satisfaction, and include in your priorities a few Delighters that will increase satisfaction dramatically. Also consider how these categories relate to your company's competitive advantage.

Customer Expectations for a Hotel Room

	Must Be	More Is Better	Delighters
Hotel Room	• Bed • Clean towels • Phone • Coffee maker	• Number/ thickness of towels • Size of room	• Fruit basket upon arrival • Balcony • Free movies

Tip Customer needs change over time. A Delighter today might be a Must Be tomorrow. In addition, different customer segments might have different needs. For example, a business traveler might consider a hotel-room iron a Must Be and the size of the desk's work surface a More Is Better. A family traveling on vacation, on the other hand, might consider free movies and video games a More Is Better characteristic.

Matrix Diagram

Finding relationships

Why use it?

To allow a team or individual to systematically identify, analyze, and rate the presence and strength of relationships between two or more sets of information.

What does it do?

- Makes patterns of responsibilities visible and clear so that there is an even and appropriate distribution of tasks
- Helps a team get consensus on small decisions, enhancing the quality and support for the final decision
- Improves a team's discipline in systematically taking a hard look at a large number of important decision factors

Types of Matrices

Most Common

- *L-shaped matrix.* Two sets of items directly compared to each other, or a single set compared to itself.

Orienting New Employees

Tasks **Resources**	Tour facility	Review personnel & safety policies	Review business values	Introduce to team members
Human resources		○	△	
Division manager			⊙	
Supervisor	△	⊙	○	○
Associates	⊙	△	△	⊙

⊙ Primary responsibility
○ Team members
△ Resources

Conclusion: Supervisors and associates have taken on the orientation role rather than the traditional human resource function.

- *T-shaped matrix*. Two sets of items compared to a common third set.

Orienting New Employees

Communicate organization spirit	◉	○	◉	◉
Communicate purpose of organization			◉	◉
Resolve practical concerns	◉	◉	○	◉
Reduce anxiety	◉	◉	◉	◉
Goals Resources Tasks	Tour facility	Review personnel & safety policies	Review business values	Introduce to team members
Human resources		○	△	
Division manager			◉	
Supervisor	△	◉	○	○
Associates	◉	△	△	◉

Responsibility	**Impact**
◉ Primary	◉ High
○ Team members	○ Medium
△ Resources	△ Low

Conclusion: The most important purpose of orientation is to reduce anxiety, and the most effective tasks focus on the personal issues.

Uncommon

- *Y-shaped matrix.* Three sets of items compared to each other. It "bends" a T-shaped matrix to allow comparisons between items that are on the vertical axes.

Rarely Used

- *X-shaped matrix.* Four sets of items compared to each other. It is essentially two T-shaped matrices placed back to back.

- *C-shaped matrix.* Shows the intersection of three sets of data simultaneously. It is a three-dimensional graphic.
- You can find more complete information on the Y-, X-, and C-shaped matrix in *The Memory Jogger Plus+*®.

How do I do it?

1. Select the key factors affecting successful implementation

- The most important step is to choose the issues or factors to be compared. The format is secondary. Begin with the right issues, and the best format will define itself. The most common use is the distribution of responsibilities within an L-shaped or T-shaped matrix.

2. Assemble the right team

- Select individuals that have the influence/power to realistically assess the chosen factors.

Tip When distributing responsibilities, include those people who will likely be involved in the assigned tasks or who can at least be part of a review team to confirm small-group results.

3. Select an appropriate matrix format

- Base your choice of format on the number of sets of items and types of comparisons you need to make.

4. Choose and define relationship symbols

- The most common symbols in matrix analysis are ⦿,○, and △. Generally they are used to indicate:

⦿ = High = 9
○ = Medium = 3
△ = Low = 1

- The possible meanings of the symbols are almost endless. The only requirement is that the team comes to a clear understanding and creates an equally clear legend with the matrix.

5. Complete the matrix

- If distributing responsibilities, use only one "primary responsibility" symbol to show ultimate accountability. All other core team members can be given secondary responsibilities.

Tip Focus the quality of the decision in each matrix cell. Do not try to "stack the deck" by consciously building a pattern of decisions. Let these patterns emerge naturally.

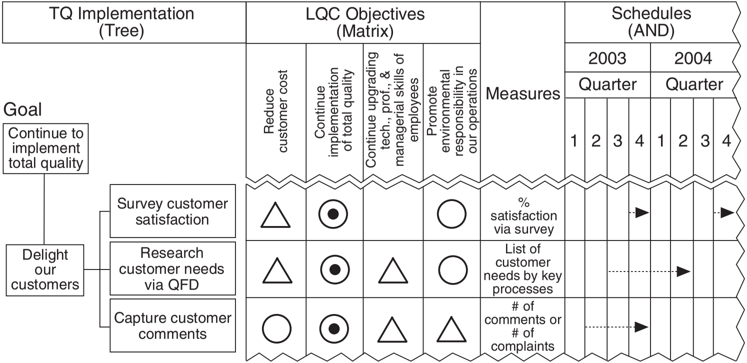
Tip Interpret the matrix using total numerical values only when it adds value. Often the visual pattern is sufficient to interpret the overall results.

Variations

The matrix is one of the most versatile tools available. The important skill to master is "matrix thinking." This approach allows a team to focus its discussion on related factors that are explored thoroughly. The separate conclusions are then brought together to create high-quality decisions. Use your creativity in determining which factors affect each other and in choosing the matrix format that will help focus the discussion toward the ultimate decision.

Matrix

Logistics Annual Plan



Goal

Continue to implement total quality

- Delight our customers
  - Survey customer satisfaction
  - Research customer needs via QFD
  - Capture customer comments

TQ Implementation (Tree)	LQC Objectives (Matrix)				Measures	Schedules (AND)							
						2003 Quarter				2004 Quarter			
	Reduce customer cost	Continue implementation of total quality	Continue upgrading tech., prof., & managerial skills of employees	Promote environmental responsibility in our operations		1	2	3	4	1	2	3	4
Survey customer satisfaction	△	⊙		○	% satisfaction via survey				▶				▶
Research customer needs via QFD	△	⊙	△	○	List of customer needs by key processes						▶		
Capture customer comments	○	⊙	△	△	# of comments or # of complaints				▶				

① See next page

⊙ = 9 Strong influence/relationship
○ = 3 Some influence/relationship
△ = 1 Weak influence/relationship
Blank = No influence/relationship

Information provided courtesy of Bell Canada

Logistics Annual Plan (cont.)

① from previous page

TQ Implementation (Tree)			Goals (AND)		Co-Responsibility (Matrix)					Cost/Benefit Analysis				Status*
			2003	2004	LQC	Departments	Boards of management	Logiqual	Other stakeholders	Resources required ($)		Tangible benefits ($)		
										03	04	03	04	
Goal Continue to implement total quality	Delight our customers	Survey customer satisfaction	75% customer satisfaction	80% customer satisfaction	◉	○	△	○	△	25K	25K			
		Research customer needs via QFD	Field trial	100% customer needs gathered	△	◉	○	◉	△	25K	25K			
		Capture customer comments	1% transactions	1.9%	△	◉			△					

◉ = 9 Prime responsibility
○ = 3 Secondary responsibility
△ = 1 Kept informed

*Status: ▨ Caution ■ Stopped □ On target

Information provided courtesy of Bell Canada

Measurement Systems Analysis (MSA)

Understanding measurement variation

Why use it?

Measurement Systems Analysis (MSA) is a type of experiment where you measure the same item repeatedly using different people or pieces of equipment. MSA is used to quantify the amount of variation in a measure that comes from the measurement system itself rather than from product or process variation. It is most commonly used in the Measure step of the DMAIC method to assess whether you need to improve your measurement system before you collect data.

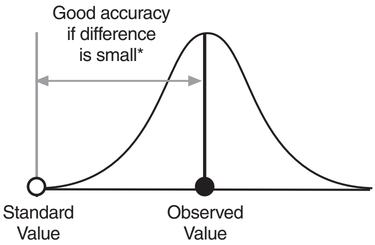
What does it do?

- Helps you to determine how much of an observed variation is due to the measurement system itself
- Helps you to determine the ways in which a measurement system needs to be improved
- Assesses a measurement system for some or all of the following five characteristics:

  1. **Accuracy**

     Accuracy is attained when the measured value has little deviation from the actual value. Accuracy is usually tested by comparing an average of repeated measurements to a known standard value for that unit of measure.

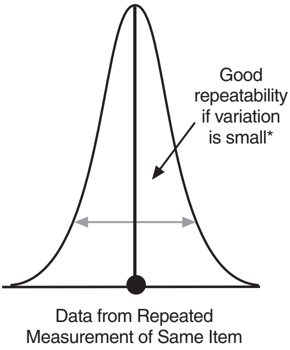
Determining Accuracy



2. **Repeatability**

Repeatability is attained when the same person taking multiple measurements on the same item or characteristic gets the same result every time.

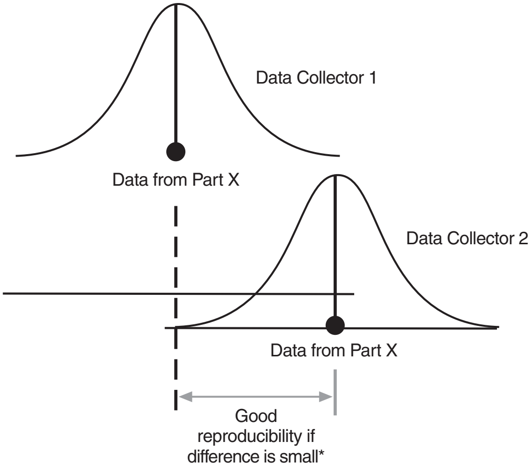
Determining Repeatability



3. Reproducibility

Reproducibility is attained when other people (or other instruments or labs) get the same results you get when measuring the same item or characteristic.

Determining Reproducibility

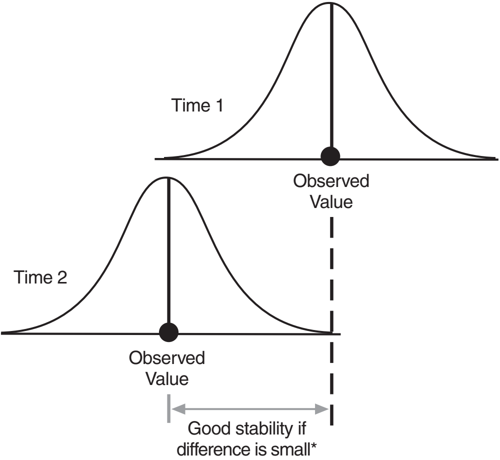


*Small relative to a) product variation and b) product tolerance (the width of the product specifications)

4. Stability

Stability is attained when measurements that are taken by one person in the same way vary little over time.

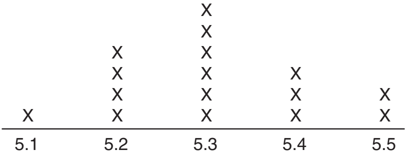
Determining Stability



5. Adequate Resolution

Adequate resolution means that your measurement instrument can give at least five (and preferably more) distinct values in the range you need to measure. For example, if you measure the heights of adults with a device that measures only to the nearest foot, you will get readings of just three distinct values: four feet, five feet, and six feet. If you needed to measure lengths between 5.1 centimeters and 5.5 centimeters, to get adequate resolution the measurement instrument you used would have to be capable of measuring to the nearest 0.1 centimeter to give five distinct values in the measurement range, as shown in the graph on the next page.

Determining Adequate Resolution



How do I do it?

1. **Conduct an experiment where different people (or machines) measure the same group of items repeatedly. This group should contain items that vary enough to cover the full range of typical variation.**

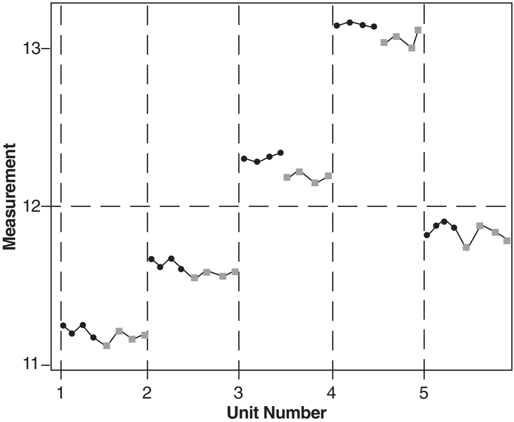
Measurements by Unit Number and Operator

Unit #	Operator	Measurement	Unit #	Operator	Measurement
1	Joe	11.34	3	Sally	12.18
1	Joe	11.29	3	Sally	12.23
1	Joe	11.33	3	Sally	12.14
1	Joe	11.24	3	Sally	12.17
1	Sally	11.19	4	Joe	13.27
1	Sally	11.29	4	Joe	13.28
1	Sally	11.21	4	Joe	13.24
1	Sally	11.24	4	Joe	13.23
2	Joe	11.65	4	Sally	13.09
2	Joe	11.60	4	Sally	13.14
2	Joe	11.67	4	Sally	13.02
2	Joe	11.56	4	Sally	13.19
2	Sally	11.50	5	Joe	11.84
2	Sally	11.55	5	Joe	11.89
2	Sally	11.51	5	Joe	11.93
2	Sally	11.55	5	Joe	11.85
3	Joe	12.31	5	Sally	11.76
3	Joe	12.28	5	Sally	11.84
3	Joe	12.31	5	Sally	11.81
3	Joe	12.34	5	Sally	11.78

Here, two people each measured five units four times.

2. Plot the data.

A Run Chart of the Measurements



● Joe — Very little difference is seen in repeated measurements
■ Sally — done by the same person or by different people.

3. Analyze the data. Use statistical techniques such as Analysis of Variance (ANOVA) to determine what portion of the variation is due to operator differences and what portion is due to the measurement process.

4. Improve the measurement process, if necessary. Do this based on what you learn from your analysis. For example, if there is too much person-to-person variation, your measurement method must be standardized for multiple persons.

The examples shown on the previous pages pertain to continuous measurement systems. A similar approach can be used for discrete measurement systems, in which items are categorized (e.g., good/bad; type of call received; reason for leaving). In these cases, you need to have a high degree of agreement on the way an item should be categorized. The best way to assess this is to have all your operators repeatedly categorize several "known" test units. Ideally, all your operators will arrive at 100% agreement: Each operator matches his or her own previous assessments, those of the other operators, and the "correct" assessments. Use any disagreements that arise as opportunities to determine and eliminate problems with your measurement system.

For example, help-desk associates might categorize incoming calls by call type. One way to test this measurement system is to have an expert categorize 100 recorded calls and then play each of the recordings twice, in random order, to four different associates. You can then document the associates' categorizations along with the expert's categorizations and analyze them for discrepancies.

Tip When doing MSA, you learn how much variation the measurement system itself contributes. Here are some guidelines for determining if that variation is too great. For continuous measurement systems, the standard deviation for the operator and measurement instrument combined should be no more than one-third the observed total standard deviation of the product. (This is derived from measuring several products and determining the standard deviation from them.) In addition, this measurement standard deviation should be no more than one-eighteenth of the specified desired product performance. For example, if the process is supposed to give results of between 5.0 and 5.18, the total measurement standard deviation should be no more than .01 (i.e., (5.18 – 5.0) ÷ 18).

No such guidelines exist for discrete measurement systems. You should investigate each measurement discrepancy (i.e., one measurer classifies an object as x, and another measurer classifies it as y) and change the process to remove the discrepancy in the future if possible.

Tip Because MSA can be quite complex, generally Six Sigma Experts or Master Six Sigma Experts are involved in the design and analysis of these experiments.

Variation

Sometimes MSA is called Gauge R&R; the *R&R* stands for Repeatability and Reproducibility.

Operational Definitions

Removing ambiguity in data collection

Why use it?

To define, for each measurement, what the key characteristic is and how to measure it.

What does it do?

- Provides a precise description for data collectors
- Removes ambiguity so that all people involved have the same understanding of the characteristic in question
- Tells how to get a value for the characteristic you are trying to measure
- Describes your way of measuring that characteristic

How do I do it?

1. **Develop a draft definition. Include what the characteristic is and how to measure it.**
   - You must be able to count defects to calculate the process sigma. In some cases, it's obvious what a defect is; in other cases, you must create a definition.
   - The definition must be specific and concrete so that different people can use it and know that their data will all be measured in the same way.
   - The definition must be measurable. This means you can assign a value (either a number or yes/no) to a data point.
   - The definition must be useful to both you and your customers. To be useful, it should relate to how the customers will judge quality and should allow a go/

no-go decision—"yes, we've met the customers' need" or "no, we haven't met the customers' need."

2. **Test the definition on a small sample of data**

3. **Modify the definition as necessary**

Tip There is no single right way to define a measure. But all your data collectors must agree on the definition you use. The more specific you are, the better.

Tip Training will help data collectors consistently apply your definition.

Examples

Operational definition for defect-free animal crackers

- A defect-free animal cracker is one with the animal completely intact. The entire body of the animal should be whole, and there should be no additional pieces of cracker (spurs, etc.) beyond the edges of the animal except for background pieces that are intended to be part of the cracker. There should be no additional gaps or holes in the animal's background.
- The embossed pattern of the animal should be clear for the entire cracker from a distance of four feet.
- The color of a defect-free animal cracker should be no lighter than the lightest cracker in the sample and no darker than the darkest cracker in the sample.

Operational definition for teller service at a bank

Customers' waiting time in line at the bank is measured, in minutes and seconds, from the point at which the customer steps behind the last person in the line to the point at which the teller greets him/her. Any wait time longer than four minutes is considered a defect.

Pareto Chart

Focus on key problems

Why use it?

To focus efforts on the problems that offer the greatest potential for improvement by showing their relative frequency or size in a descending bar graph.

What does it do?

- Helps a team to focus on those causes that will have the greatest impact if solved
- Based on the proven Pareto principle: 20% of the sources cause 80% of any problem
- Displays the relative importance of problems in a simple, quickly interpreted, visual format
- Helps prevent "shifting the problem" where the "solution" removes some causes but worsens others
- Progress is measured in a highly visible format that provides incentive to push on for more improvement

How do I do it?

1. **Decide which problem you want to know more about**

   Example: Consider the case of HOTrep, an internal computer network help line: Why do people call the HOTrep help line; what problems are people having?

2. **Choose the causes or problems that will be monitored, compared, and rank ordered by brainstorming or with existing data**

   a) Brainstorming

   Example: What are typical problems that users ask about on the HOTrep help line?

b) Based on existing data

Example: What problems in the last month have users called about on the HOTrep help line?

3. **Choose the most meaningful unit of measurement, such as frequency or cost**

- Sometimes you don't know before the study which unit of measurement is best. Be prepared to do both frequency and cost.

  Example: For the HOTrep data the most important measure is frequency because the project team can use the information to simplify software, improve documentation or training, or solve bigger system problems.

4. **Choose the time period for the study**

- Choose a time period that is long enough to represent the situation. Longer studies don't always translate to *better* information. Look first at volume and variety within the data.
- Make sure the scheduled time is typical in order to take into account seasonality or even different patterns within a given day or week.

  Example: Review HOTrep help line calls for 10 weeks (May 22–August 4).

5. **Gather the necessary data on each problem category either by "real time" or reviewing historical data**

- Whether data is gathered in "real time" or historically, check sheets are the easiest method for collecting data.

  Example: Gathered HOTrep help line calls data based on the review of incident reports (historical).

Tip *Always* include with the source data and the final chart the identifiers that indicate the source, location, and time period covered.

6. **Compare the relative frequency or cost of each problem category**

Example:

Problem Category	**Frequency**	**Percent (%)**
Bad configuration	3	1
Boot problems	68	33
File problems	8	4
Lat. connection	20	10
Print problems	16	8
Reflection hang	24	12
Reflection sys. integrity	11	5
Reflections misc.	6	3
System configuration	16	8
System integrity	19	9
Others	15	7
Total	**206**	

7. **List the problem categories on the horizontal line and frequencies on the vertical line**

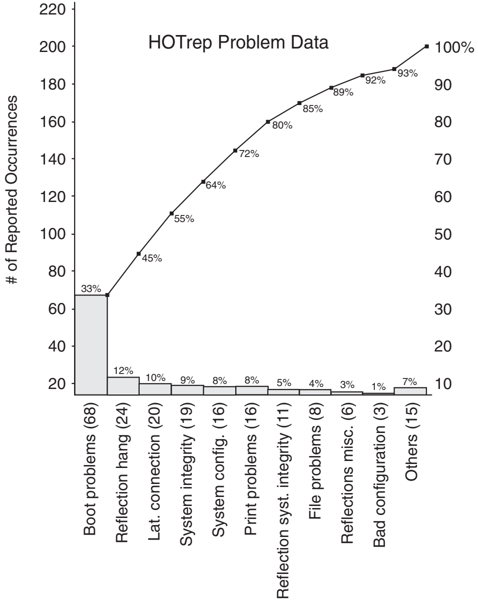
   - List the categories in descending order from left to right on the horizontal line with bars above each problem category to indicate its frequency or cost. List the unit of measure on the vertical line.

8. **(Optional) Draw the cumulative percentage line showing the portion of the total that each problem category represents**

   a) On the vertical line, (opposite the raw data, #, $, etc.), record 100% opposite the total number and 50% at the halfway point. Fill in the remaining percentages drawn to scale.

   b) Starting with the highest problem category, put a dot or an x at the upper righthand corner of the bar.

   - Add the total of the next problem category to the first and draw a dot above that bar showing both the cumulative number and percentage. Connect the dots and record the remaining cumulative totals until 100% is reached.



Information provided courtesy of SmithKline Beecham

9. Interpret the results

- *Generally*, the tallest bars indicate the biggest contributors to the overall problem. Dealing with these problem categories first therefore makes common sense. *But*, the most frequent or expensive is not always the most important. Always ask: What has the most impact on the goals of our business and customers?

Variations

The Pareto Chart is one of the most widely and creatively used improvement tools. The variations used most frequently are listed below. Examples are shown on pages 184–188.

- A. **Major Cause Breakdowns** in which the "tallest bar" is broken into subcauses in a second, linked Pareto.
- B. **Before and After** in which the "new Pareto" bars are drawn side by side with the original Pareto, showing the effect of a change. It can be drawn as one chart or two separate charts.
- C. **Change the Source of Data** in which data is collected on the same problem but from different departments, locations, equipment, and so on, and shown in side-by-side Pareto Charts.
- D. **Change Measurement Scale** in which the same categories are used but measured differently. Typically "cost" and "frequency" are alternated.

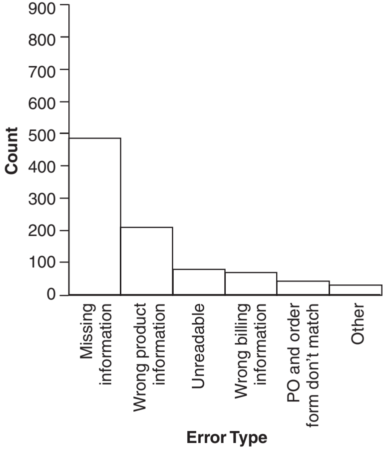
Pareto Chart Stratification

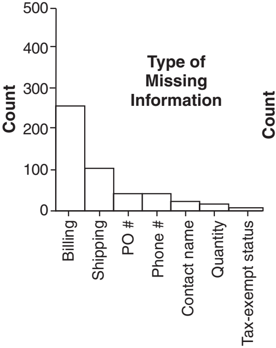
As described in the Data Collection section, stratification can provide useful insight into what is actually happening in your process. Some Pareto Charts can be stratified.

Example

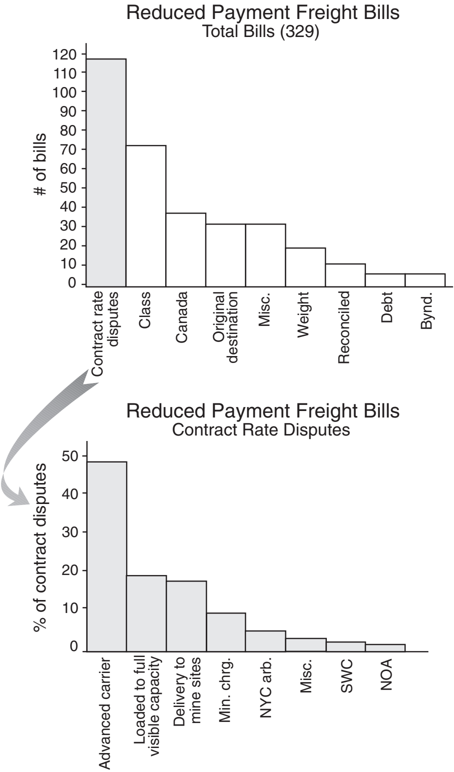
The team at XYZ Company decided to focus on errors made on faxed orders, since more errors occurred with those orders than with e-mail or web orders. To get an idea of the types of errors that occurred, the team randomly selected 400 orders from a group of 4000+ orders and catalogued the types of errors encountered. They counted almost 900 errors made on the 400 orders. They plotted their data in three different ways, as shown in the Pareto Charts on the next page.

Errors Made on 400 Orders



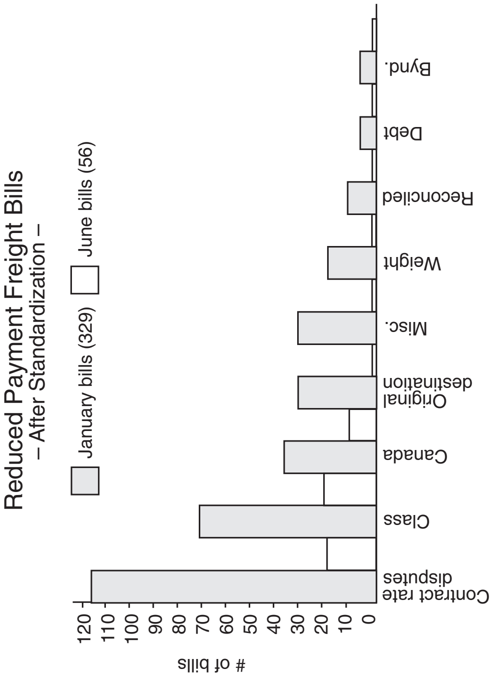


A. Major Cause Breakdowns



Information provided courtesy of Goodyear

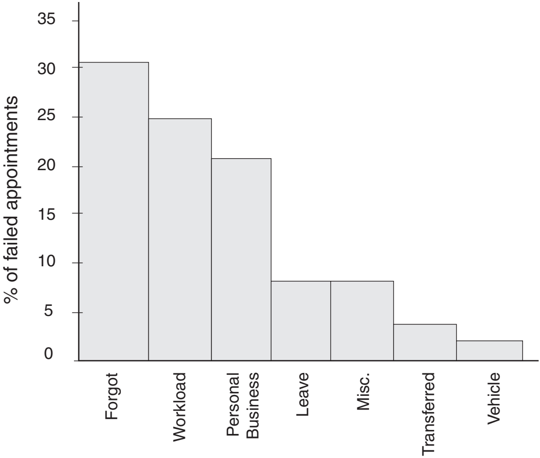
B. Before and After



Information provided courtesy of Goodyear

C. Change the Source of Data

Reason for Failed Appointments
Source of Data is: Shore Commands

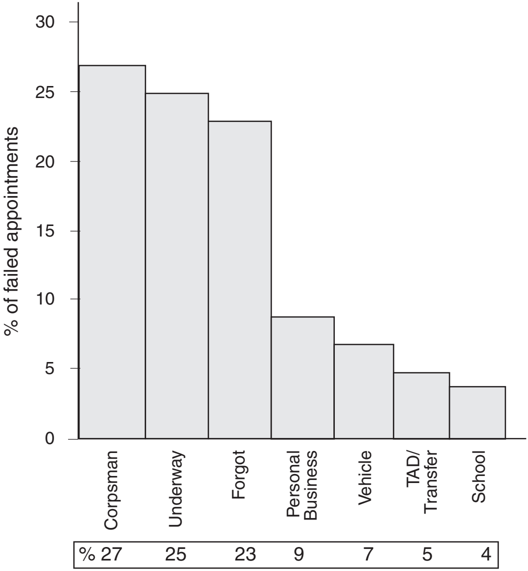


% 31	25	21	8	8	4	2

Information provided courtesy of
U.S. Navy, Naval Dental Center, San Diego

C. Change the Source of Data

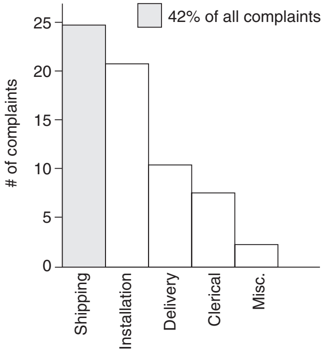
Reason for Failed Appointments
Source of Data is: Fleet Commands



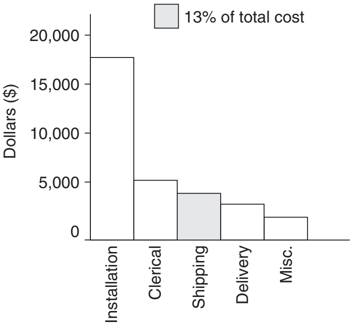
Information provided courtesy of U.S. Navy, Naval Dental Center, San Diego

D. Change Measurement Scale

Field Service Customer Complaints



Cost to Rectify Field Service Complaints



Prioritization Matrices

Weighing your options

Why use it?

To narrow down options through a systematic approach of comparing choices by selecting, weighting, and applying criteria.

What does it do?

- Quickly surfaces basic disagreements so they may be resolved up front
- Forces a team to focus on the best thing(s) to do, and not everything they could do, dramatically increasing the chances for implementation success
- Limits "hidden agendas" by surfacing the criteria as a necessary part of the process
- Increases the chance of follow-through because consensus is sought at each step in the process (from criteria to conclusions)
- Reduces the chances of selecting someone's "pet project"

How do I do it?

There are three methods for constructing Prioritization Matrices. The outline that follows indicates typical situations for using each method. Only the "Full Analytical Criteria Method" is discussed here. The others are covered fully in *The Memory Jogger Plus+*®.

Full Analytical Criteria Method

Typically used when:

- Smaller teams are involved (3–8 people).
- Options are few (5–10 choices).
- There are relatively few criteria (3–6 items).
- Complete consensus is needed.
- The stakes are high if the plan fails.

Consensus Criteria Method

This method follows the same steps as in the Full Analytical Criteria Method except the Consensus Criteria Method uses a combination of weighted voting, and ranking is used instead of paired comparisons.

Typically used when:

- Larger teams are involved (8 or more people).
- Options are many (10–20 choices).
- There is a significant number of criteria (6–15 items).
- Quick consensus is needed to proceed.

Combination ID/Matrix Method

This method is different from the other two methods because it is based on cause and effect, rather than criteria.

Typically used when:

- Interrelationships among options are high, and finding the option with the greatest impact is critical.

Full Analytical Criteria Method

1. **Agree on the ultimate goal to be achieved in a clear, concise sentence**

   - If no other tools are used as input, produce a clear goal statement through consensus. This statement strongly affects which criteria are used.

Choose the most enjoyable vacation
for the whole family

2. **Create the list of criteria**

   - Brainstorm the list of criteria or review previous documents or guidelines that are available, e.g., corporate goals, budget-related guidelines.

- Cost
- Educational value
- Diverse activity
- Escape reality

Tip The team *must reach consensus* on the final criteria and their meanings, or the process is likely to fail!

3. **Using an L-shaped matrix, weight all criteria against each other**

   - Reading across from the vertical axis, compare each criterion to those on the horizontal axis.
   - Each time a weight (e.g., 1, 5, 10) is recorded in a row cell, its reciprocal value (e.g., $\frac{1}{5}$, $\frac{1}{10}$) must be recorded in the corresponding column cell.
   - Total each horizontal row and convert to a relative decimal value known as the "criteria weighting."

Criterion vs. Criterion

Criteria \ Criteria	Cost	Educ. value	Diverse activity	Escape reality	Row Total	Relative Decimal Value
Cost		$\frac{1}{5}$	$\frac{1}{10}$	5	5.3	.15
Educ. value	5		$\frac{1}{5}$	5	10.2	.28
Diverse activity	10	5		5	20	.55
Escape reality	$\frac{1}{5}$	$\frac{1}{5}$	$\frac{1}{5}$		.60	.02
				Grand Total	36.1	

1 = Equally important
5 = More important
10 = Much more important
$^1/_5$ = Less Important
$^1/_{10}$ = Much less important

Row Total
Rating scores added
Grand Total
Row totals added
Relative Decimal Value
Each row total ÷ by the grand total

4. **Compare ALL options relative to each weighted criterion**
   - *For each criterion*, create an L-shaped matrix with all of the options on both the vertical and horizontal axis and the criteria listed in the lefthand corner of the matrix. ***There will be as many options matrices as there are criteria to be applied.***
   - Use the same rating scale (1, 5, 10) as in Step 3, *BUT* customize the wording for each criterion.
   - The relative decimal value is the "option rating."

Options vs. Each Criterion (Cost Criterion)

Cost	Disney World	Gettysburg	New York City	Uncle Henry's	Row Total	Relative Decimal Value
Disney World	■	$\frac{1}{5}$	5	$\frac{1}{10}$	5.3	.12
Gettysburg	5	■	10	$\frac{1}{5}$	15.2	.33
New York City	$\frac{1}{5}$	$\frac{1}{10}$	■	$\frac{1}{10}$	.40	.01
Uncle Henry's	10	5	10	■	25	.54
				Grand Total	45.9	

1 = Equal cost
5 = Less expensive
10 = Much less expensive
1/5 = More expensive
1/10 = Much more expensive

Continue Step 4 through three more Options/Criterion matrices, like this:

Escape reality

Crt.	Options			
Options				

Diverse activity

Crt.	Options			
Options				

Educational value

Crt.	Options			
Options				

Tip The whole number (1, 5, 10) must always represent a desirable rating. In some cases this may mean "less," e.g., cost; in others this may mean "more," e.g., tasty.

5. **Using an L-shaped summary matrix, compare each option based on all criteria combined**
    - List all criteria on the horizontal axis and all options on the vertical axis.
    - In each matrix cell multiply the "criteria weighting" of each criterion (decimal value from Step 3) by the "option rating" (decimal value from Step 4). This creates an "option score."
    - Add each option score across all criteria for a row total. Divide each row total by the grand total and convert to the final decimal value. Compare these decimal values to help you decide which option to pursue.

Summary Matrix
Options vs. All Criteria

Criteria / **Optns.**	Cost (.15)	Educational value (.28)	Diverse activity (.55)	Escape reality (.02)	Row Total	Relative Decimal Value (RT ÷ GT)
Disney World	.12 x .15 (.02)	.24 x .28 (.07)	.40 x .55 (.22)	.65 x .02 (.01)	.32	.32
Gettysburg	.33 x .15 (.05)	.37 x .28 (.10)	.10 x .55 (.06)	.22 x .02 (0)	.22	.22
New York City	.01 x .15 (0)	.37 x .28 (.10)	.49 x .55 (.27)	.12 x .02 (0)	.37	.38
Uncle Henry's	.54 x .15 (.08)	.01 x .28 (0)	.01 x .55 (.01)	.01 x .02 (0)	.09	.09
				Grand Total	1.00	

.54 x .15
(from Step 4 matrix) (from Step 3 matrix)

(.08)
Option score

6. Choose the best option(s) across all criteria

Tip While this is more systematic than traditional decision making, it is not a science. Use common sense and judgment when options are rated very closely, but be open to non-traditional conclusions as well.

Variations

See *The Memory Jogger Plus+®* for full explanations of both the Consensus Criteria Method and the Combination ID/Matrix Method. The Full Analytical Criteria Method, illustrated in this book, is recommended because it encourages full discussion and consensus on critical issues. The Full Analytical Criteria Method is a simplified adaptation of an even more rigorous model known as the Analytical Hierarchy Process. It is based on the work of Thomas Saaty, which he describes in his book *Decision Making for Leaders*. In any case, use common sense to know when a situation is important enough to warrant such thorough processes.

Another type of matrix your team can use to select the best and strongest idea or concept from dozens or hundreds of possibilities is Stuart Pugh's New Concept Selection tool. For details, see pages 193 through 206 of *The Idea Edge*™.

Prioritization

Choosing a Standard Corporate Spreadsheet Program

① Weighting criteria (described in Step 3)

This is a portion of a full matrix with 14 criteria in total.

Criteria	Best use of hardware	Ease of use	Maximum functionality	Best performance	Total (14 criteria)	Relative Decimal Value
Best use of hardware	■	.20	.10	.20	3.7	.01
Ease of use	5.0	■	.20	.20	35.4	.08
Maximum functionality	10.0	5.0	■	5.0	69.0	.17
Best performance	5.0	5.0	.20	■	45.2	.11
				Grand Total (14 criteria)	418.1	

Information provided courtesy of Novacor Chemicals

Note: This constructed example, illustrated on three pages, represents only a portion of the prioritization process and only a portion of Novacor's spreadsheet evaluation process. Novacor Chemicals assembled a 16-person team, comprised mainly of system users and some information systems staff. The team developed and weighted 14 standard criteria and then applied them to choices in word processing, spreadsheet, and presentation graphics programs.

This example continued on the next page

Choosing a Standard Corporate Spreadsheet Program (cont.)

② Comparing options (described in Step 4)

These are just 2 of 14 matrices.

Best integration –internal	Program A	Program B	Program C	Total	Relative Decimal Value
Program A		1.00	1.00	2.00	.33
Program B	1.00		1.00	2.00	.33
Program C	1.00	1.00		2.00	.33
			Grand Total	6.00	

Lowest ongoing cost	Program A	Program B	Program C	Total	Relative Decimal Value
Program A		.10	.20	.30	.02
Program B	10.00		5.00	15.00	.73
Program C	5.00	.20		5.20	.25
			Grand Total	20.50	

Information provided courtesy of Novacor Chemicals

This example continued on the next page

Choosing a Standard Corporate Spreadsheet Program (cont.)

③ Summarize Option Ratings Across All Criteria (described in Step 5)

This is a portion of a full matrix with 14 criteria in total.

Criteria / Options	Easy to use (.08)	Best integration int. (.09)	Lowest ongoing cost (.08)	Total (across 14 criteria)	Relative Decimal Value
Program A	.03 (.01)	.33 (.03)	.02 (0)	.16	.18
Program B	.48 (.04)	.33 (.03)	.73 (.06)	.30	.33
Program C	.48 (.04)	.33 (.03)	.25 (.02)	.44	.49
			Grand Total	.90	

Information provided courtesy of Novacor Chemicals

Result: Program C was chosen. Even though 14 out of the 16 team members were not currently using this program, the prioritization process changed their minds, and prevented them from biasing the final decision.

Process Management Chart

Ensuring your changes stay in place

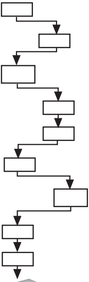
Why use it?

To combine your plan for completing a work process together with the Check and Act phases of the PDCA Cycle and to monitor the implementation of the solutions you selected. (For details on the PDCA Cycle, see pages 11 through 13 of *The Problem Solving Memory Jogger*™.)

What does it do?

- Communicates the new process or procedures to other team members
- Indicates what type of corrective action will be taken when a trigger or indicator occurs

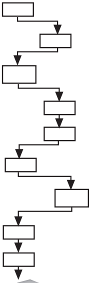
A Sample Process Management Chart

Plan/Do	Check	Act
Flowchart	**Indicators**	**Corrective Actions**
	Plot time on each order; should be ≤ two hours; check for special causes.	If time exceeds two hours, alert Sam immediately; organize investigation.
	Count errors.	If more than one per order, stop process and contact Sam.

The plan is typically captured as a flowchart.

The middle column describes what you will check in the process to monitor its quality.

The third column describes how the process operators should react, depending on what they find in the measures.

Plan/Do	**Check**	**Act**
Flowchart	**Indicators**	**Corrective Actions**
	Plot time on each order; should be ≤ two hours; check for special causes.	If time exceeds two hours, alert Sam immediately; organize investigation.
	Count errors.	If more than one per order, stop process and contact Sam.

How do I do it?

1. Complete the Plan/Do section of the chart

- You can use any type of flowchart you want for the Plan/Do column. Typically, a Deployment Flowchart works best for administrative or service processes, while an Activity Flowchart works best for manufacturing processes.
- The key is to capture the essential steps of the process you are studying.
- For each key step, show how the operation should be done or provide a reference to a document that describes the step.

2. Complete the Check section of the chart

- For manufacturing processes, the Check column often describes any technical specifications that have to be met. For administrative and service processes, this column usually describes quality criteria that have been defined for the process.
- *Key process indicators* are the characteristics to be monitored in each critical step (e.g., elapsed time, completeness, presence of errors, temperature).
- For each key process indicator, describe any important targets, numerical limits, tolerances, or specifications to which the process should conform if it is running well (e.g., eight hours from receipt, all boxes checked, 125°F–135°F). These standards can come from customers, regulatory policies, or process knowledge.
- For each key process indicator, describe how the monitored data should be recorded (e.g., checklist, Run Chart, Control Chart, Scatter Diagram). Describe, if necessary, who should record the data and how.

3. Complete the Act section of the chart

- Address damage control.
  - Who should do what with the output of the defective process?
  - What should be done for customers who receive the defective output?
  - What adjustments should be made to ensure that there will be no defects in the next iteration?

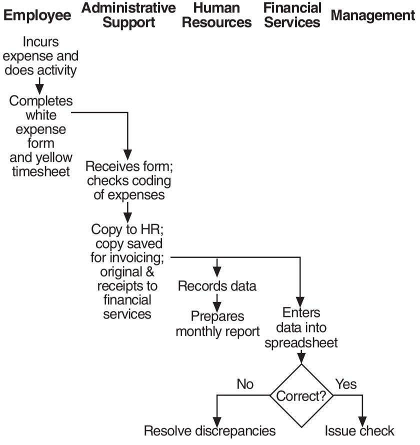
- Address procedures for process adjustment.
  - What must be done to gain sufficient understanding of this process so that the operators know what adjustments and accommodations are routinely necessary to prevent a recurrence of this problem?
- Address procedures for systems improvement.
  - Who in the organization needs what data in what form to be able to make a sound decision regarding new systems or remedies at deeper levels in the organization (i.e., changes in basic designs or policies)?

Tip In manufacturing, Process Management Charts typically include references to manufacturing specifications, physical attributes to be checked, and so on. By contrast, as shown in this example, administrative or service Process Management Charts are more often concerned with whose responsibility it is to carry out different tasks and what standards should be used for those tasks.

Example

An organization was having trouble with the processing of time-and-expense reports. A cross-functional group got together and agreed on who would do what, defined various codes and methods to be used, and created standard forms to be used. The cross-functional group used the document shown on the next page to communicate with all the organization's employees about the new procedures.

A Process Management Chart for Processing Expense Records

The Plan for Doing the Work	Checking the Work	Act: Response to Results
Flowchart	**Key Process Indicators**	**Corrective Actions**
	100% inspection for standards: 1. Received by 5 p.m. Tues. (on-site) or 5 p.m. Wed. (by mail). 2. Operational definitions of expenses used. 3. Complete information provided. 4. Columns added and summary completed.	Correct form or return to employee. Discuss corrections with employee. Provide training if needed.
	Receipts behind form, stapled in upper left corner.	Correct form or return to employee. Discuss corrections with employee. Provide training if needed.
	HR does 100% inspection for proper use of time-coding vacation, leave, and holiday expenses used.	If unclear about budget codes, check with manager.
	FS responsible for: 1. All charges allocated. 2. Proper use of budget codes.	If incorrect: 1. Work with Administrative Support to resolve. 2. Track common areas of problems and report to manager monthly.

Process Sigma

Measuring performance from the customer's perspective

Why use it?

To measure how much variation there is in a process relative to customer specifications. The process-sigma value is based on the number of defects per million opportunities, or DPMO. It is an expression of process yield (based on the DPMO). If you find a lot of variation relative to customer specifications, your process has a low process-sigma value. If you find little variation relative to customer specifications, your process has a high process-sigma value.

Historical data indicates a change of 1.5 in a process-sigma value when short-and long-term process capabilities are compared. This shift is due to drift in the mean of a process over time, which increases overall process variation, thus reducing the sigma value. Typically, the short-term capability and sigma value are determined. Subtracting 1.5 from the short-term value provides a good estimate of long-term process capability based on short-term measurements. The tables in this section give the long-term sigma value for short-term data. To obtain the actual sigma value for the data, subtract 1.5 from the values shown.

What does it do?

- Provides a more sensitive indicator than percent yield. "Yield" refers to how much of your process output is acceptable to your customers. A 99% yield sounds good, but the 6,210 DPMO value at this quality level shows that there is significant room for improvement.

Process Sigma Values

These are estimates of long-term sigma values. For actual sigma values, subtract 1.5 from these values.

Percent	DPMO	σ
99%	6,210	4.0
99.87%	1,350	4.5
99.977%	233	5.0
99.9997%	3.4	6.0

- Focuses on defects. Even a single defect reflects a failure in your customers' eyes.
- Makes comparisons easier by using a common metric. Because the three processes in the table below are measured with different metrics, it is difficult to tell which process performed best.

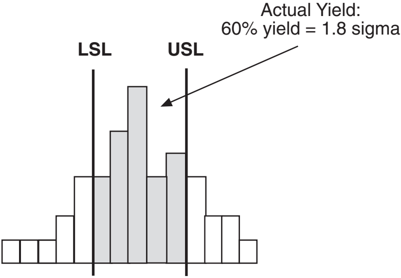
Three Processes with Different Metrics

Process	Transactions per Month	Performance
Calls handled	14,000	Average 10% require transfers
Credits processed	75	Average cycle time of three days
Daily reports	28–31	Nine errors per day

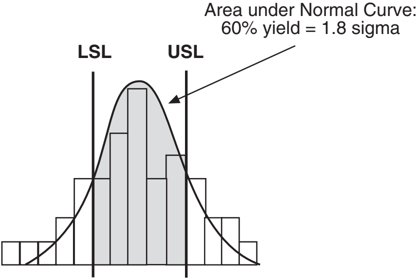
How do I do it?

There are two methods for calculating process sigma. Method 1 involves looking up the actual yield in a process-sigma conversion table like the one at the end of this section. Method 2 involves looking up a normal approximation of yield in a process-sigma table. Method 1 is detailed below. If you need to use Method 2, see your Six Sigma Expert or Master Six Sigma Expert for pointers.

Method 1 for Calculating Process Sigma



Method 2 for Calculating Process Sigma



Method 1

1. **Review each of the Critical To Quality characteristics (CTQs) that you have selected for the project.**

2. **For each CTQ, clearly define what a defect is. In general, a defect is any aspect of a product or service that does not meet a customer specification. In some industries, a customer specification is also referred to as a *customer tolerance*.**

3. **Define a defect opportunity ("O") for each CTQ. In general, a defect opportunity is a measurable chance for a defect to occur.**

   - A defect opportunity occurs each time the product, service, or information is handled. It is the point at which a customer quality requirement is either met or missed.

   Tip Remember that a defect opportunity is based on the quality characteristic that is not met—not on the number of ways in which it can be missed. For example, you should not list both "incorrect name" and "misspelled name" as defect opportunities for a form. Rather, list one defect opportunity associated with the quality characteristics of "correct name."

   Tip Whenever possible, stick with the same definitions of defect opportunities that were used in the past. The focus of process sigma is on improvement, and it is impossible to measure improvement if what you consider to be a defect is constantly changing.

   Tip Simple processes have few defect opportunities; complex processes have more. For example, a simple sub-process like posting a payment has only two defect opportunities: incorrect post and late post. More complex processes, like structuring a deal, have many more opportunities—perhaps one each for the accuracy and timeliness of key research figures, several for the timeliness and professionalism of key customer interactions, and so on. However, if the process sigma for complex processes in your organization has always been determined from a few simple defect opportunities determined by the customer, it might be best not to change your measurement system.

Tip Make sure that you count only those defects that can be reasonably expected to happen or that have happened in the past. Also make sure that each defect opportunity matters to the customer.

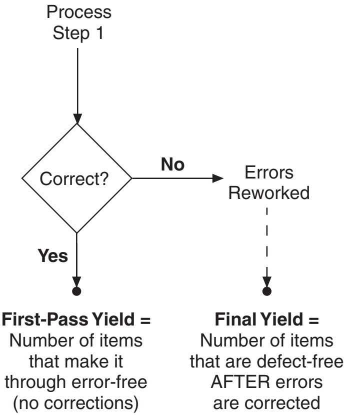
Tip It is important for the number of defect opportunities to remain constant throughout your analysis. The number of opportunities is an ingredient of the yield calculation used to determine process sigma. If the number of opportunities changes, your calculations of yield before and after a change won't be comparable.

Sample Yield-Calculation Factors

Situation	CTQ	Unit	Defect Opportunities per Unit
Credit card bill	Accurate amounts	Each bill	One per transaction
	Correct address	Each bill	One per bill

4. **Determine the number of units produced ("N"). A unit is the item produced or processed.**
5. **Determine the total number of defects made ("D"). Include any defects that are made and then later fixed. By including the defects that later get fixed, you are calculating your process sigma based on the first-pass yield of the process, not the final yield. The first-pass yield provides the most accurate picture of the process because:**
   - It is difficult to "inspect away" defects.
   - It is very costly to fix errors.
   - It reveals a process's true improvement potential.

First-Pass Yield vs. Final Yield



6. **Calculate defects per opportunity ("DPO"). DPO = D/(N × O).**

7. **Calculate yield. Yield = (1 – DPO) × 100.**

8. **Look up your process sigma in the Process-Sigma Conversion Table on page 212.**

Example:

A Sample Process-Sigma Calculation

100 units
2 opportunities per unit
7 defects

$$\text{Yield} = \left(1 - \frac{7}{100 \times 2}\right) \times 100$$

$$= (1 - .035) \times 100 = 96.5\% = 3.3\sigma \text{ (long-term)}$$

1. Determine number of defect opportunities per unit. **O** =	2
2. Determine number of units processed. **N** =	100
3. Determine total number of defects made; include defects made and later fixed. **D** =	7
4. Calculate defects per opportunity. **DPO** = $\frac{D}{N \times O}$ =	.035
5. Calculate yield. **Yield** = (1 – DPO) × 100 =	96.5
6. Look up process sigma in the conversion table. **Long-term process sigma** =	3.3
Actual process sigma =	1.8

Tip Method 1 is reliable only if there is a sufficient number of defects and non-defects. You must have at least five of each category for this method to work.

Tip In some cases the main concern is with the overall process yield only. In such cases, set one specification for the process as a whole, and determine one overall process-sigma cycle time for the entire process (e.g., "complete the process within three days").

In other cases, there might be separate specifications for different steps. Then you need to know how to determine the process sigma for each step and combine them into an overall process sigma for the entire process.

Process-Sigma Conversion Table

These are estimates of long-term sigma values. For actual sigma values, subtract 1.5 from these values.

Yield	DPMO	Process Sigma	Yield	DPMO	Process Sigma
99.9999%	1	6.27	92.00%	80,000	2.91
99.9997%	3	6.04	91.00%	90,000	2.84
99.9990%	10	5.77	90.00%	100,000	2.78
99.99%	100	5.22	85.00%	150,000	2.54
99.90%	1,000	4.59	80.00%	200,000	2.34
99.80%	2,000	4.38	75.00%	250,000	2.17
99.70%	3,000	4.25	70.00%	300,000	2.02
99.60%	4,000	4.15	65.00%	350,000	1.89
99.50%	5,000	4.08	60.00%	400,000	1.75
99.40%	6,000	4.01	55.00%	450,000	1.63
99.30%	7,000	3.96	50.00%	500,000	1.50
99.20%	8,000	3.91	45.00%	550,000	1.37
99.10%	9,000	3.87	40.00%	600,000	1.25
99.00%	10,000	3.83	35.00%	650,000	1.11
98.00%	20,000	3.55	30.00%	700,000	0.98
97.00%	30,000	3.38	25.00%	750,000	0.83
96.00%	40,000	3.25	20.00%	800,000	0.66
95.00%	50,000	3.14	15.00%	850,000	0.46
94.00%	60,000	3.05	10.00%	900,000	0.22
93.00%	70,000	2.98			

Yield Conversion Table

These are estimates of long-term sigma values. For actual sigma values, subtract 1.5 from these values.

Sigma	DPMO	Yield
6	3.4	99.99966%
5.9	5.4	99.99946%
5.8	8.5	99.99915%
5.7	13	99.99866%
5.6	21	99.9979%
5.5	32	99.9968%
5.4	48	99.9952%
5.3	72	99.9928%
5.2	108	99.9892%
5.1	159	99.984%
5	233	99.977%
4.9	337	99.966%
4.8	483	99.952%
4.7	687	99.931%
4.6	968	99.90%
4.5	1,350	99.87%
4.4	1,866	99.81%
4.3	2,555	99.74%
4.2	3,467	99.65%
4.1	4,661	99.53%
4	6,210	99.38%
3.9	8,198	99.18%
3.8	10,724	98.9%
3.7	13,903	98.6%
3.6	17,864	98.2%
3.5	22,750	97.7%
3.4	28,716	97.1%
3.3	35,930	96.4%
3.2	44,565	95.5%
3.1	54,799	94.5%
3	66,807	93.3%
2.9	80,757	91.9%
2.8	96,801	90.3%
2.7	115,070	88.5%
2.6	135,666	86.4%
2.5	158,655	84.1%
2.4	184,060	81.6%
2.3	211,855	78.8%
2.2	241,964	75.8%
2.1	274,253	72.6%
2	308,538	69.1%
1.9	344,578	65.5%
1.8	382,089	61.8%
1.7	420,740	57.9%
1.6	460,172	54.0%
1.5	500,000	50.0%
1.4	539,828	46.0%
1.3	579,260	42.1%
1.2	617,911	38.2%
1.1	655,422	34.5%
1	691,462	30.9%
0.9	725,747	27.4%
0.8	758,036	24.2%
0.7	788,145	21.2%
0.6	815,940	18.4%
0.5	841,345	15.9%
0.4	864,334	13.6%
0.3	884,930	11.5%
0.2	903,199	9.7%
0.1	919,243	8.1%

Regression

Quantifying the relationship between two variables

Why use it?

To investigate suspected correlations by generating an equation that quantifies the relationship.

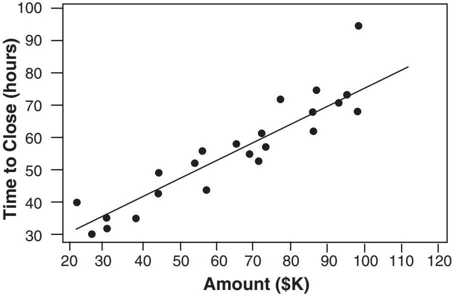
What does it do?

- Explains the relationship through an equation for a line, curve, or surface
- Explains the variation in y values
- Enables you to predict the impact of controlling a process variable (x)
- Enables you to predict future process performance for certain values of x
- Helps you identify the vital few x's that drive y (see the section on the y = f (x) formula)
- Helps you manipulate process conditions to generate desirable results (if x is controllable) and/or avoid undesirable results

For linear regressions (i.e., when the relationship is defined by a line), the regression equation is represented as $y = b_o + b_1x$, where b_o = intercept (i.e., the point where the line crosses x = 0) and b_1 = slope (i.e., rise over run, or change in y per unit increase in x).

Note: You might be accustomed to expressing the equation for a line as y = mx + b, where m = slope and b = intercept. We use a different notation here, for reasons that will become clear when you do multiple regression. (See the graph at the end of this section.)

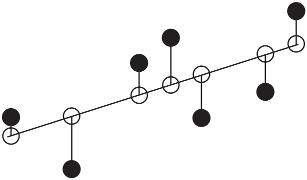
An Example of Linear Regression



How do I do it?

Use the least squares method, where you determine the regression equation by using a procedure that minimizes the total squared distance from all points to the line.

This method finds the line where the squared vertical distance from each data point to the line is as small as possible (or the “least”). This means that the method minimizes the “square” of all the residuals.



Least squares method

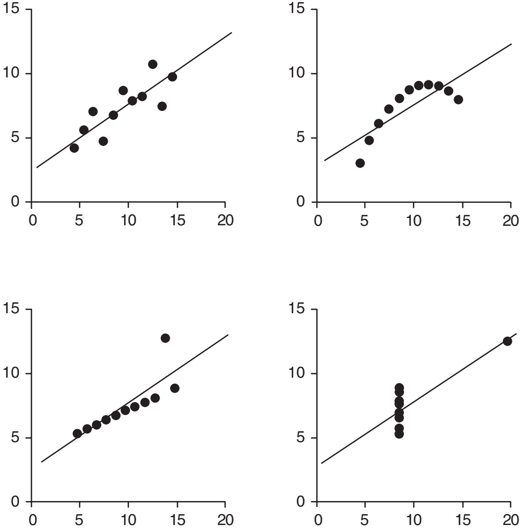
1. Measure vertical distance from points to line.
2. Square the figures.
3. Sum the total squared distance.
4. Find the line that minimizes that sum.

Data (both x and y values) are used to obtain the b_o and b_1 values, and the b_o and b_1 values establish the equation.

1. **Plot the data on a Scatter Diagram (See page 228 for details)**

   Tip Be sure to plot your data before doing regression. The charts below show four sets of data that have the same regression equation: $y = 3 + 0.5x$. Obviously, there are four completely different relationships.

Four Plots of the Same Equation



2. **Measure the vertical distance from the points to the line**
3. **Square the figures**
4. **Sum the total squared distance**
5. **Find the line that minimizes the sum**

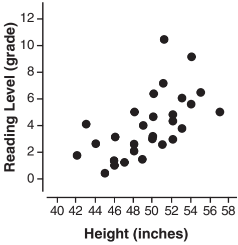
Tip Generally a computer program is used to generate the "best fit" line that represents the relationship between x and y. This work is typically performed by a Six Sigma Expert and is shown here for overview purposes only.

Tip The following sets of terms are often used interchangeably:

- Regression equation and regression line.
- Prediction equation and prediction line.
- Fitted line, or fits, and model.

Tip When two variables show a relationship on a scatter plot, they are said to be correlated, but this does not necessarily mean they have a cause/effect relationship. *Correlation* means two things vary together. *Causation* means changes in one variable cause changes in the other.

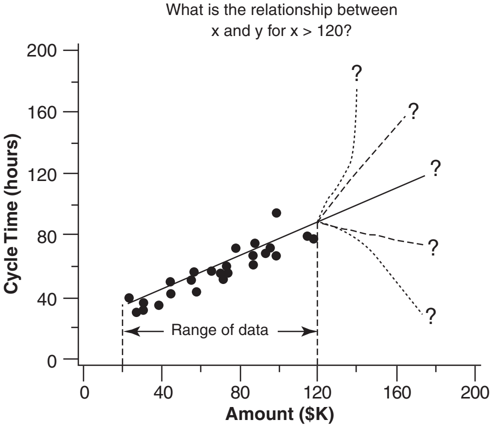
Correlated Variables



Both variables were influenced by a third variable, age.

Tip *Extrapolation* refers to making predictions outside the range of the x data. It's a natural desire, but it can be very risky. Predictions from regression equations are more reliable for x's within the range of the observed data. Extrapolation is less risky if you have a theory, process knowledge, or other data to guide you.

An Example of Extrapolation

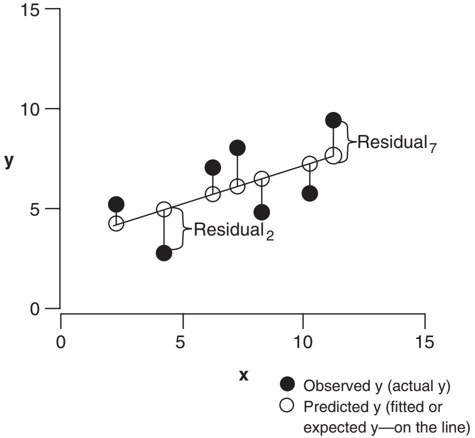


The residual is the leftover variation in y after you use x to predict y. The residual represents common-cause (i.e., random and unexplained) variation. You determine a residual by subtracting the predicted y from the observed y.

Residuals are assumed to have the following properties:

- Not related to the x's.
- Stable, independent, and not changing over time.
- Constant and not increasing as the predicted y's increase.
- Normal (i.e., bell-shaped) with a mean of zero.

An Example of Residuals

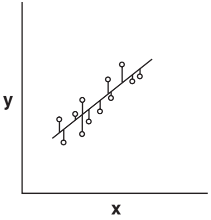


Your Six Sigma Expert will be responsible for checking each of these assumptions. If the assumptions do not hold, the regression equation might be incorrect or misleading.

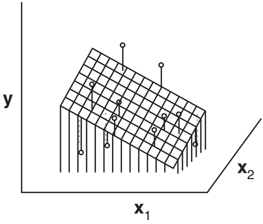
> ***Tip*** Other types of regression your team might need to use are shown in the following graph.

Other Types of Regression

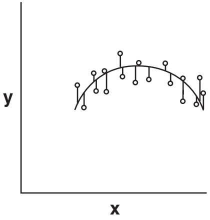
Simple Linear (One x)



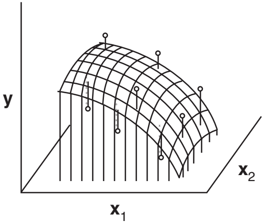
Multiple (Two or More x's)



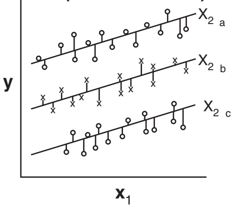
Curvilinear (One x)



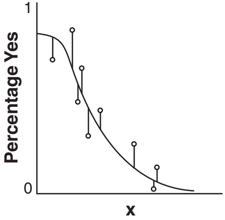
Curvilinear (Two or More x's)



Using Indicator Variables (for Discrete x's)



Logistic (for Discrete y's)



Run Chart

Tracking trends

Why use it?

To allow a team to study observed data from a Check Sheet or other data-collection source to analyze trends or patterns over a specified period of time.

What does it do?

- Monitors the performance of one or more processes over time to detect trends, shifts, or cycles
- Allows a team to compare a performance measure before and after implementation of a solution to measure its impact
- Focuses attention on vital changes in the process
- Tracks useful information for predicting trends

How do I do it?

1. **Decide on the process performance measure**

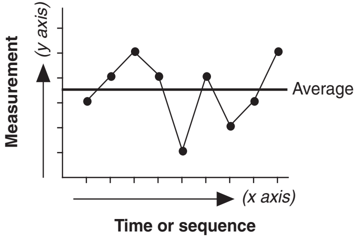
2. **Gather data**
   - Generally, collect 20–25 data points to detect meaningful patterns.

3. **Create a graph with a vertical line (y axis) and a horizontal line (x axis)**
   - On the vertical line (y axis), draw the scale related to the variable you are measuring.
     - Arrange the y axis to cover the full range of the measurements and then some, e.g., $1\frac{1}{2}$ times the range of data.
   - On the horizontal line (x axis), draw the time or sequence scale.

4. Plot the data

- Look at the data collected. If there are no obvious trends, calculate the average or arithmetic mean. The average is the sum of the measured values divided by the number of data points. The median value can also be used but the mean is the most frequently used measure of the "centering" of the sample. (See Data Points for more information on averages.) Draw a horizontal line at the average value.

Tip Do not redraw this line every time new data is added. Only when there has been a major change in the process or prevailing conditions should the average be recalculated and redrawn, and then only using the data points after the verified change.



5. Interpret the Chart

- Note the position of the average line. Is it where it should be relative to a customer need or specification? Is it where you want it relative to your business objective?

Tip A danger in using a Run Chart is the tendency to see every variation in data as being important. The Run Chart should be used to focus on truly vital changes in the process. Simple tests can be used to look for meaningful trends and patterns. These tests are found in the Control Charts section. Remember that for more sophisticated uses, a Control Chart is invaluable since it is simply a Run Chart with statistically based limits.

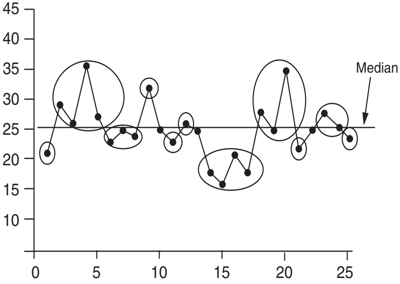
Variation

Like Control Charts, Run Charts can be used to assess whether there are any signs of special-cause variation. In general, to use a Run Chart you follow five steps:

1. **Collect twenty or more data values over time.**
2. **Plot the data in time order.**
3. **Pencil in the median line.**
4. **Count the runs above and below the median. A *run* is a series of points on the same side of the median; a series can be of any length, from one point to many points.**
5. **Check for special causes.**

If you see any signs of a special cause, try to determine what it is and then work to remove it permanently. If the process is stable, continue with your data analysis.

Sample Run Chart



Twenty data points not on median out of eleven runs

Note: Points on the median are ignored. They do not add to or interrupt a run.

A run ends anytime the connecting line crosses the median. The number of runs you should expect to see in a stable process depends on the number of data points. The chart below shows how many runs you can expect when only common-cause variation is present. The twenty data points not on the median for eleven runs in the sample Run Chart is well within the range listed in the chart below. Thus, based on this test, you can reasonably conclude there are no special causes of variation.

Expected Numbers of Runs

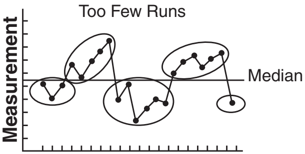
Number of Data Points Not on Median	Lower Limit for Number of Runs	Upper Limit for Number of Runs	Number of Data Points Not on Median	Lower Limit for Number of Runs	Upper Limit for Number of Runs
10	3	8	34	12	23
11	3	9	35	13	23
12	3	10	36	13	24
13	4	10	37	13	25
14	4	11	38	14	25
15	4	12	39	14	26
16	5	12	40	15	26
17	5	13	41	16	26
18	6	13	42	16	27
19	6	14	43	17	27
20	6	14	44	17	28
21	7	15	45	17	29
22	7	16	46	17	30
23	8	16	47	18	30
24	8	17	48	18	31
25	9	17	49	19	31
26	9	18	50	19	32
27	9	19	60	24	37
28	10	19	70	28	43
29	10	20	80	33	48
30	11	20	90	37	54
31	11	21	100	42	59
32	11	22	110	46	65
33	11	22	120	51	70

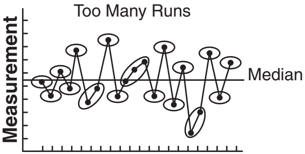
In addition to checking the number of runs, other tests for special causes you can use with Run Charts are as follows:

- Too many runs.
- Too few runs.
- Six or more points in a row continuously increasing or decreasing. This indicates a trend.
- Eight or more points in a row on the same side of the median. This indicates a shift. When counting runs on the same side of the center line, ignore any points on the center line.
- Fourteen or more points in a row alternating up and down. When counting runs up or down, ignore any points that repeat the preceding value. If two points in a row have the same value, ignore the second point.

Below are illustrations of each of these special causes:

Other Tests for Special Causes





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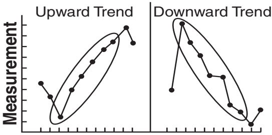
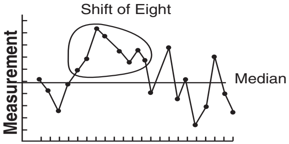
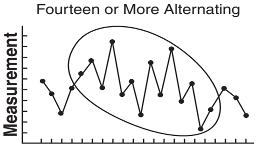
Other Tests for Special Causes (cont.)

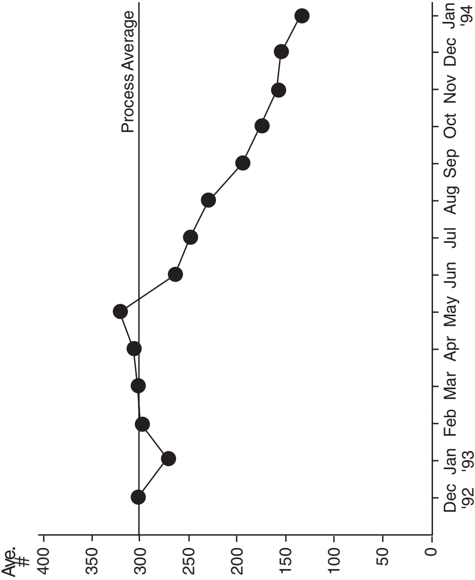






Run

Average Number of Days for Determining Eligibility for Services



Information provided courtesy of Georgia State Department of Human Resources, Division of Rehabilitation Services

Note: Eligibility requirements changed in May, making it much simpler for the department staff to make determinations. The trend is statistically significant because there are six or more consecutive points declining.

Scatter Diagram

Measuring relationships between variables

Why use it?

To study and identify the possible relationship between the changes observed in two different sets of variables.

What does it do?

- Supplies the data to confirm a hypothesis that two variables are related
- Provides both a visual and statistical means to test the strength of a potential relationship
- Provides a good follow-up to a Cause & Effect Diagram to find out if there is more than just a consensus connection between causes and the effect

How do I do it?

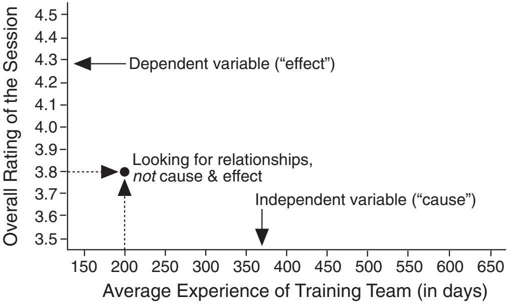
1. **Collect 50–100 paired samples of data that you think may be related and construct a data sheet**

Course	Average Session Rating (on a 1–5 scale)	Average Experience of Training Team (days)
1	4.2	220
2	3.7	270
3	4.3	270
•	•	•
•	•	•
•	•	•
40	3.9	625

Theory: There is a possible relationship between the number of days of experience the training team has received and the ratings of course sessions.

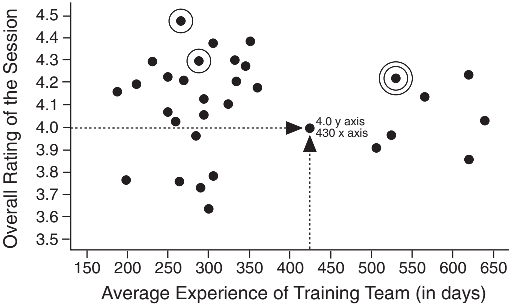
2. Draw the horizontal (x axis) and vertical (y axis) lines of the diagram

- The measurement scales generally increase as you move up the vertical axis and to the right on the horizontal axis.



3. Plot the data on the diagram

- If values are repeated, circle that point as many times as is appropriate.

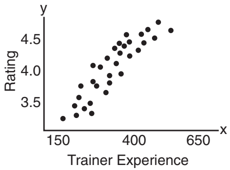


Information provided courtesy of Hamilton Standard

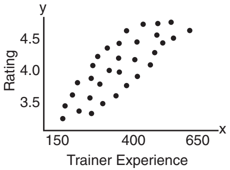
4. Interpret the data

- There are many levels of analysis that can be applied to Scatter Diagram data. Any basic statistical process control text, like Kaoru Ishikawa's *Guide to Quality Control,* describes additional correlation tests. It is important to note that all of the examples in this chapter are based on straight-line correlations. There are a number of nonlinear patterns that can be routinely encountered, e.g., $y = e^x$, $y = x^2$. These types of analyses are beyond the scope of this book.
- The following five illustrations show the various patterns and meanings that Scatter Diagrams can have. The example used is the training session assessment previously shown. The patterns have been altered for illustrative purposes. Pattern #3 is the actual sample.

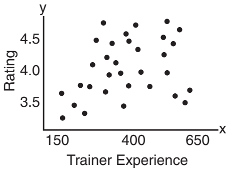
Tip The Scatter Diagram *does not predict* cause-and-effect relationships. It only shows the strength of the relationship between two variables. The stronger the relationship, the greater the likelihood that change in one variable will affect change in another variable.



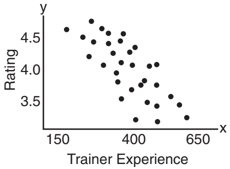
1. Positive Correlation. An increase in y may depend on an increase in x. Session ratings are likely to increase as trainer experience increases.



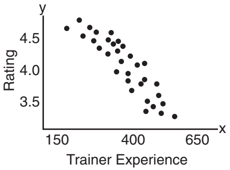
2. Possible Positive Correlation. If x is increased, y may increase somewhat. Other variables may be involved in the level of rating in addition to trainer experience.



3. No Correlation. There is no demonstrated connection between trainer experience and session ratings.



4. Possible Negative Correlation. As x is increased, y may decrease somewhat. Other variables, besides trainer experience, may also be affecting ratings.



5. Negative Correlation. A decrease in y may depend on an increase in x. Session ratings are likely to fall as trainer experience increases.

Variations

Stratifying a Scatter Diagram

You can stratify Scatter Diagrams to uncover clues about relationships between variables. In the example below, when the data is stratified by branch, no relationship is apparent between mistakes made on invoices and cycle time. Without stratification, mistakes made on invoices would have been mistakenly believed to be related to cycle time, when the actual relationship is between branch and cycle time.

A Stratified Scatter Diagram

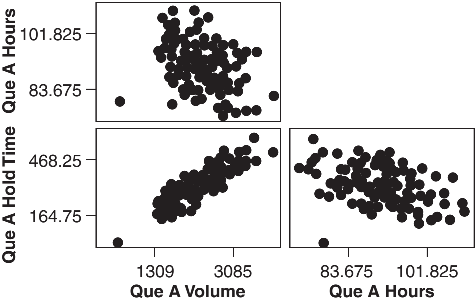
After stratifying the plot, we see no correlation, but a difference due to branch.

Scatter Diagram Matrix

Many statistical software packages enable you to produce a matrix showing multiple Scatter Diagrams on one graph, called a Scatter Diagram Matrix. To continue the example mentioned above, the team finds that the average hold times are related to daily call volume. The team then decides to investigate whether hold times are also related to production hours (i.e., the number of hours staffed).

The following Scatter Diagram Matrix helps the team determine if there is a relationship among hold time, production hours, and call volume.

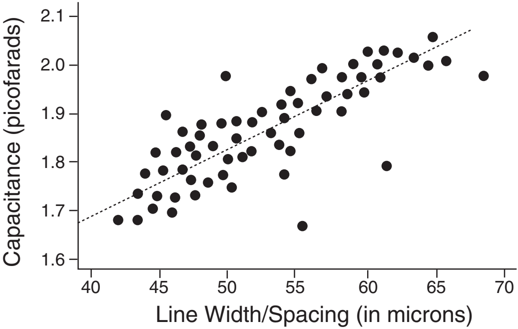
A Scatter Diagram Matrix



In the lower left diagram, the data points hug a diagonal line going from low values for each variable to high values, indicating a strong positive relationship between call volume and hold time. The other two diagrams show weaker negative relationships between the other variables: Higher call-volume values seem to be associated with lower values of production hours, and higher values of production hours seem to be associated with lower hold-time values.

Scatter

Capacitance vs. Line Width



Information provided courtesy of AT&T

Note: This Scatter Diagram shows that there is a strong positive relationship between these two variables in producing microelectronic circuits. Since capacitance measures a critical performance of a circuit, anything that affects it positively or negatively is also critical. The diagram shows that line width/spacing is something to watch closely, perhaps using a Control Chart or another type of statistical process control (SPC) tool.

SIPOC

Understanding the process at a high level

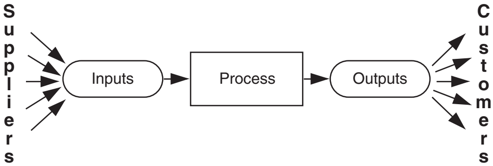
Why use it?

To develop a high-level understanding of the process that is under study, including the upstream and downstream links.

What does it do?

- Defines project boundaries (i.e., starting and ending points)
- Describes where to collect data
- Identifies suppliers and customers (i.e., stakeholders who need to be considered as part of your project)
- Identifies inputs and outputs (i.e., what is flowing in and flowing out of the process)
- Helps to support process thinking within your organization

The SIPOC Process



How do I do it?

Many teams have trouble working on a SIPOC (Suppliers, Inputs, Process, Outputs, and Customers) diagram in order (i.e., starting with Suppliers and then moving onto Inputs, and so on). The following steps are often a more useful sequence for identifying SIPOC elements.

1. **Start by identifying the starting and ending points of the process you are studying**

2. **State the purpose of the process. Ask:**
   - Why does this process exist?
   - What is the purpose of this process?
   - What is the outcome?

3. **Fill in the main process steps between the starting and ending points so you have a total of five to seven steps. Think of your diagram as a top-level flowchart, where the focus is on main steps, not details. Here you are not concerned with loops or errors. To identify the main steps in the process, ask the following questions:**
   - What happens to each input?
   - What conversion activities take place?

   Tip When doing a SIPOC analysis, be sure to keep the process to between five and seven steps. You want to portray an overall picture of the major actions that occur in the process, not delve into details.

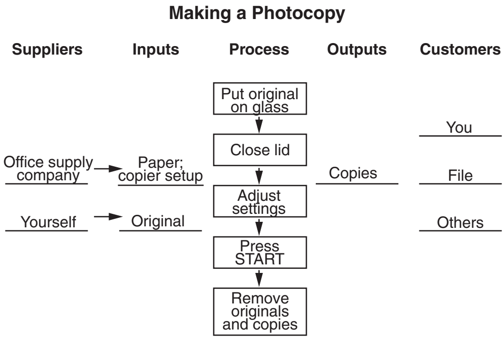
4. **Identify outputs from the process. Outputs can include physical products, documents, information, services, and decisions. To identify outputs, ask the following questions:**

- What product does this process make?
- At what point does this process end?
- What information does this process produce?

5. **Identify the customers for each output by asking:**
    - Who uses the products/information supplied from this process?
    - Who are the customers of this process?
6. **Identify the key process inputs. Here it helps to try to think of what actually flows through your process and what is being transformed. Is it a physical part or raw materials? A form? Documentation? A sample? Most process inputs are primarily in the form of materials and information, but they can also include ideas, labor, and environment. To identify inputs, ask:**
    - What flows into the process?
    - What triggers the process to start?
7. **Identify the key suppliers for each input by asking:**
    - Where does the information or material we work on come from? Who are our suppliers?
    - What do they supply?
    - Where do they affect the process flow?
    - What effect do they have on the process and on the outcome?

    Tip Some suppliers might provide more than one input, and a process often has more than one output.

A Sample SIPOC Diagram



Tip After you complete the SIPOC diagram for your project, take a few minutes to review the charter and make any modifications that you think are appropriate.

Six Sigma Storyboard

Maintaining records and communicating progress

Why use it?

To track data, decisions, and actions and create a graphical or pictorial record of your DMAIC project.

What does it do?

- Facilitates decision making
- Helps maintain forward momentum
- Helps prevent rework
- Because they provide a quick, visual summary of a team's work, the elements of a Storyboard can also be used as presentation materials. Many organizations keep them permanently on record so other employees can have access to the improvement team's work.

How do I do it?

1. Maintain records throughout the life of your project

- Agendas and meeting notes provide a permanent record of what issues are discussed at meetings—particularly what "to do" items are generated and what decisions are reached.
- Records of customer interviews or surveys provide verbal data that will help to shape your effort. Your management sponsor or others in the organization might find this data helpful to also use for future efforts.

- Data-collection sheets provide the source for your analysis. You should keep them at least until the project is completed.
- Plans help you identify the components of a task, track your progress, and communicate your progress to others. Documented plans help you evaluate whether you did what you intended to do; they can also provide the basis for standardized work plans.
- Data charts help you understand your data, enable you to compare the outcome of the improvement effort with the initial situation, and provide a baseline for monitoring the process and making future improvements.

2. Create a Six Sigma Storyboard

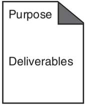
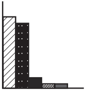
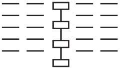
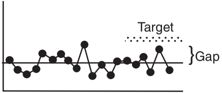
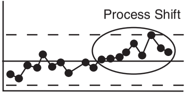
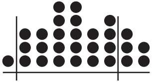
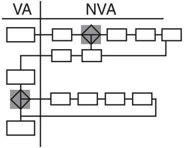
- Develop a pictorial record of the DMAIC steps by using the template on pages 241–243.

Tip Keep your text brief, use a lot of graphics, and make sure your graphics effectively communicate your message.

3. Present your Storyboard to others

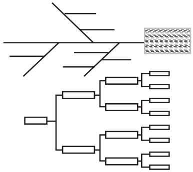
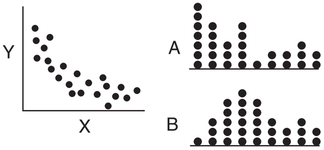
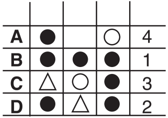
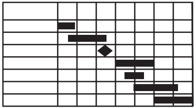
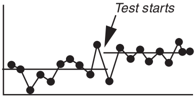
Process-sigma project participants are often asked to introduce others in the organization to improvement concepts, explain a concept or tool they used, and present examples of their applications of various concepts and tools. Often this is done as a formal presentation.

Storyboard Template

Step	Text	Typical Graphics
Define	Discussion of charter	**Charter**  **VOC Data**  **SIPOC Map**  **Other Charts Depicting Gap** 
Measure	Interpretation of data and graphics	**Time Plot** or **Control Chart** showing patterns in variation over time  **Frequency Plot** (Histogram) showing patterns in distribution and **process-sigma calculations**  $\sigma = 1.4$ **Pareto Chart** showing relative importance of different components of the problem  **Flowchart** depicting current process 

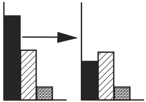
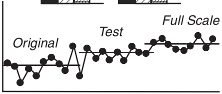
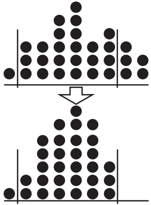
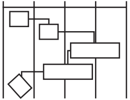
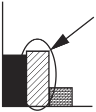
Continued on next page

Storyboard Template (cont.)

Step	Text	Typical Graphics	
Analyze	Reasons for selecting causes for verification Interpretation of verification data	**C&E Diagram** (or other tool showing potential causes identified) 	**Scatter Plot, Stratified Frequency Plots, or Tables** showing verification data 
Improve	Explanations of criteria Comments on plans and tests	**Solution Matrix** showing ranked criteria and scoring for each solution option 	**Plans** for implementation  **Results** of pilot tests 

Continued on next page

Storyboard Template (cont.)

Step	Text	Typical Graphics
Improve	Interpretation of analysis of results and methods	**Before and After Data** Comparing results of implementation with data already collected in the Define, Measure, or Analyze steps. Plots should be drawn to same scale.   s = 1.4 s = 3.6 
Control	Comments on training plans and ongoing monitoring responsibilities	**Samples of standardization documentation** including revised flowcharts, QC process charts, etc. 
	Summary of learnings and suggestions for next steps Plans for celebration and recognition	*Learnings* | | | | Charts showing areas that still need improvement 

Taguchi Loss Function

Reducing variation around a customer target

Why use it?

To understand the benefit of continually reducing variation, even when customer specifications are met.

What does it do?

- Conceptually defines the loss associated with variation
- Illustrates the difference between variation and specifications. The amount of *variation* in a process tells you what the process is capable of achieving. *Specifications* tell you what you want a process to be able to achieve.
- Describes why meeting customer specifications is not enough

Traditionally, organizations focused only on achieving product and service levels that were within the customer-specified range (often called specifications, tolerances, or requirements). Under that mind-set, anything that fell within the limits was thought to be equally good; as long as the product or service was within customer specifications, there was no loss.

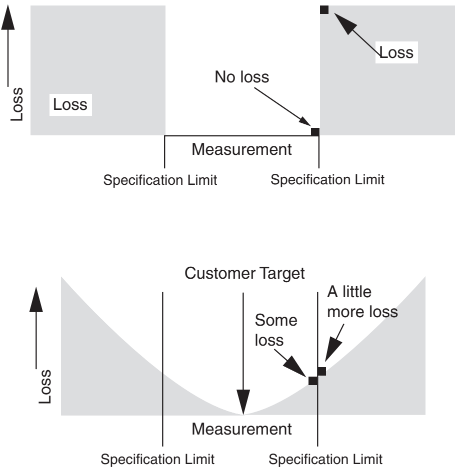
However, Genichi Taguchi, a renowned Japanese scholar, taught the business world that there is loss any time a product or service varies from a defined target. This loss comes from sources that include the following:

- Increased wear or decreased performance from parts that don't fit together precisely.
- Increased service calls for repairs.

- Repeated calls for information or for re-delivery of a service.
- Loss resulting from excess waiting or from excess inventory when a product or service is not delivered at the specified time.

According to the traditional view (see the figure below), any value between the specifications is equally good. According to the Taguchi view, on the other hand, anytime a characteristic deviates from the target, some loss occurs. The bigger the deviation, the bigger the loss (Taguchi, 1960).

Loss: Traditional View vs. Taguchi View



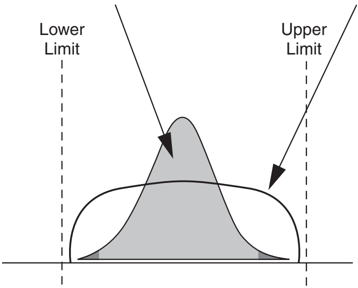
Taguchi Case Study

- In the 1980s, Ford Motor Company outsourced the construction of a subassembly to several of its own plants and to a Japanese manufacturer.
- Both the U.S. and Japan plants produced parts that conformed to specifications; both groups of parts had zero defects.
- Over the next few years, however, the number of warranty claims on the U.S.-built product was far higher than that for the Japanese product.
- The difference? The Japanese had worked to control and reduce variation—that is, get the parts as close to the actual target as possible. The U.S. plants had simply produced "within spec."
- The Japanese product was far more consistent; parts fit together better. The result: better performance and lower costs due to less scrap, less rework, and less inventory.

The Taguchi Case Study

Distribution of subassembly parts from Japanese supplier: "*Control the process to get as close to target as possible.*"

Distribution of subassembly parts from American suppliers: "*Everything between spec limits is equally good.*"



Tollgate Review

Ensuring the project stays on track

Why use it?

To review progress and check for key deliverables at the completion of each step of the DMAIC method. The project sponsor reviews the Storyboard to make sure sufficient rigor has been used and provides a formal sign-off to show the step has been satisfactorily completed.

What does it do?

- Provides guidance and direction for the project team
- Establishes a common understanding of the efforts to date and enables you to monitor progress
- Ensures alignment and reinforces priorities
- Provides ongoing coaching and instruction about the project
- Recognizes the project team's efforts and fosters intrinsic motivation for improvements

How do I do it?

1. **A few days before the tollgate review, the project team prepares a Storyboard that shows the work completed for the current DMAIC step and sends it to the project sponsor. The sponsor then studies the Storyboard in preparation for the tollgate review.**

2. **During the tollgate review, the team members do the following:**

   - Present a brief background review to reiterate the project's purpose and importance.

- State the purpose of this tollgate review and highlight the required outcomes.
- Report on the project's progress since the last review. This includes doing the following:
  - Using the Storyboard as the presentation framework.
  - Emphasizing the logic of the work done during each step and conclusions drawn from analysis of the data.
  - Highlighting changes in the charter, expected results, or risks.
  - Presenting issues, options, decisions needed, or recommendations for discussion.
  - Presenting plans for next steps.

3. **After the presentation, the sponsor does the following:**
   - Reinforces the strengths of the team's work.
   - Asks questions about the team's logic and conclusions.
   - Offers reactions and suggestions, focusing on one or two specific suggestions for improving the logic or data.
   - Makes decisions.
   - Conveys appreciation for the team's progress.
4. **Before the review is over, the sponsor and the project team work together to:**
   - Review decisions, action items, and agreements about next steps.
   - Evaluate the review, identifying what was useful and any ways the review could be improved.

Tree Diagram

Mapping the tasks for implementation

Why use it?

To break any broad goal, graphically, into increasing levels of detailed actions that must or could be done to achieve the stated goals.

What does it do?

- Encourages team members to expand their thinking when creating solutions. Simultaneously, this tool keeps everyone linked to the overall goals and subgoals of a task
- Allows all participants (and reviewers outside the team) to check all of the logical links and completeness at every level of plan detail
- Moves the planning team from theory to the real world
- Reveals the *real* level of complexity involved in the achievement of any goal, making potentially overwhelming projects manageable, as well as uncovering unknown complexity

How do I do it?

1. Choose the Tree Diagram goal statement

Goal: Increase workplace suggestions

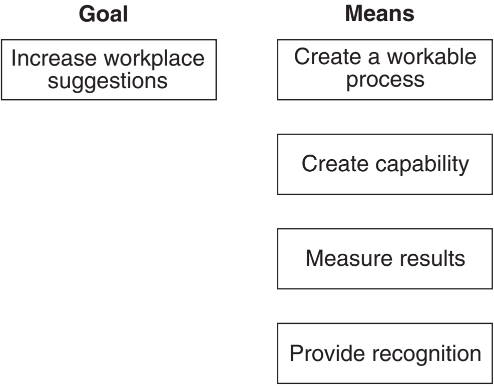
- Typical sources:
  - The root cause/driver identified in an Interrelationship Digraph (ID).
  - An Affinity Diagram with the headers as major subgoals.
  - Any assignment given to an individual or team.
- When used in conjunction with other management and planning tools, the most typical source is the root cause/driver identified in the ID.

Tip Regardless of the source, work hard to create—through consensus—a clear, action-oriented statement.

2. **Assemble the right team**
   - The team should consist of action planners with detailed knowledge of the goal topic. The team should take the Tree only to the level of detail that the team's knowledge will allow. Be prepared to hand further details to others.
   - Four to six people is the ideal group size, but the Tree Diagram is appropriate for larger groups as long as the ideas are visible and the session is well facilitated.

3. **Generate the major Tree headings, which are the major subgoals to pursue**
   - The simplest method for creating the highest, or first level of detail, is to brainstorm the major task areas. These are the major "means" by which the goal statement will be achieved.

- To encourage creativity, it is often helpful to do an "Action Affinity" on the goal statement. Brainstorm action statements and sort into groupings, but spend less time than usual refining the header cards. Use the header cards as the Tree's first-level subgoals.



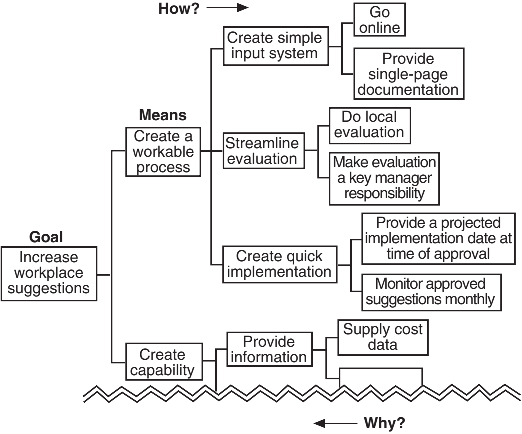
Tip Use Post-it® Notes to create the levels of detail. Draw lines only when the Tree is finished. This allows it to stay flexible until the process is finished. The Tree can be oriented from left to right, right to left, or top down.

Tip Keep the first level of detail broad, and avoid jumping to the lowest level of task. Remember: "If you start with what you already know, you'll end up where you've already been."

4. Break each major heading into greater detail

- Working from the goal statement and first-level detail, placed either to the extreme left, right, or top of the work surface, ask of each first-level item, "What needs to be addressed to achieve the goal statement?"

  Repeat this question for each successive level of detail.
- Stop the breakdown of each level when there are assignable tasks or the team reaches the limit to its own expertise. Most Trees are broken out to the third level of detail (not counting the overall goal statement as a level). However, some subgoals are just simpler than others and don't require as much breakdown.



5. **Review the completed Tree Diagram for logical flow and completeness**
   - At each level of detail, ask, "Is there something obvious that we have forgotten?"
   - As the Tree breaks down into greater detail (from general to specific) ask, "If I want to accomplish these results, do I really need to do these tasks?"
   - As the Tree builds into broader goals (from the specific to the general) ask, "Will these actions actually lead to these results?"
   - Draw the lines connecting the tasks.

   Tip The Tree Diagram is a great communication tool. It can be used to get input from those outside the team. The team's final task is to consider proposed changes, additions, or deletions and to modify the Tree as is appropriate.

Variations

The Process Decision Program Chart (PDPC) is a valuable tool for improving implementation through contingency planning. The PDPC, based on the Tree Diagram, involves a few simple steps.

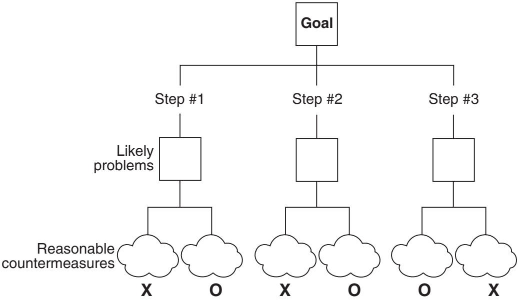
1. **Assemble a team closest to the implementation**

2. **Determine proposed implementation steps**
   - List 4–10 broad steps and place them in sequence in the first Tree level.

3. **Branch likely problems off each step**
   - Ask, "What could go wrong?"

4. **Branch possible and reasonable responses off each likely problem**

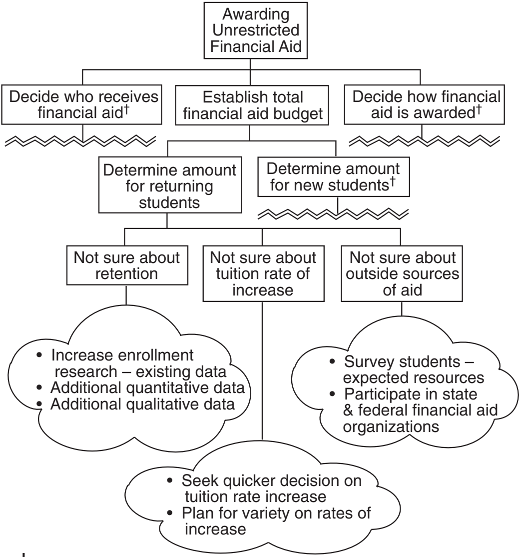
5. Choose the most effective countermeasures and build them into a revised plan



X = Difficult/impossible
O = Selected

PDPC (Tree Variation)

Awarding Unrestricted Financial Aid



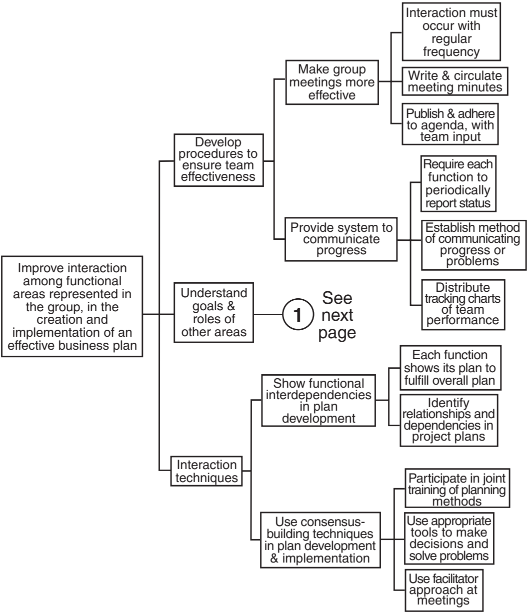
† Further information exists but is not shown

Information provided courtesy of St. John Fisher College

Note: The PDPC surfaced a lack of accurate information as a major problem. By anticipating this and filling the most critical information gaps, the budget can be more accurate.

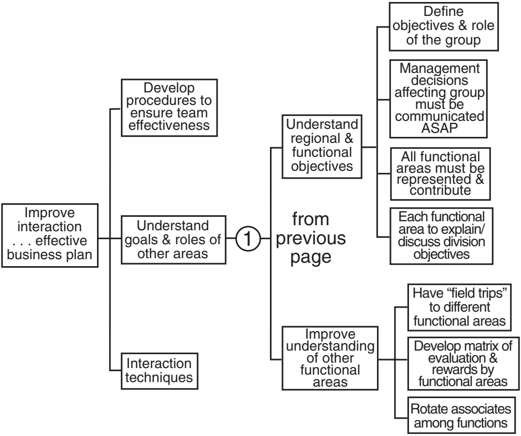
Tree

Improve
Business Planning Interaction



Information provided courtesy of Goodyear

Improve Business Planning Interaction (continued)



Information provided courtesy of Goodyear

Voice of the Customer (VOC) Data-Collection System

Understanding customer needs

Why use it?

To identify the key drivers of customer satisfaction. It is only through understanding your customers' thought process while they are making their purchasing decisions and while they are using your products or services that you can effectively design, deliver, and improve them. The term *voice of the customer*, or VOC, is used to describe your customers' needs and their perceptions of the quality of your products or services.

What does it do?

- Properly focuses your improvement project
- Provides data to help you develop appropriate measurements
- Helps the team decide what products and services to offer
- Identifies critical features for those products and services, known as Critical-To-Quality characteristics, or CTQs
- Provides a baseline measure of customer satisfaction against which to measure improvement
- Identifies the key drivers of customer satisfaction

How do I do it?

1. **Identify your customers and what you need to know about their needs.**
   - In a SIPOC (Suppliers, Inputs, Process, Outputs, and Customers) context, a customer is anyone who uses or benefits from the output of your process.
     - One of your customers is the next step that occurs in a process after the process delivers an output.
     - Only your customer can define what a defect is.
   - In a marketing context, the term *customer* is usually restricted to the people and groups outside an organization who purchase and/or use a company's products or services.
   - Ask yourself the following questions:
     - What are the outputs of our process? Who are the customers of that output?
     - Are there particular groups of customers whose needs are especially important to our organization?

   Tip You must decide which of the above definitions of *customer* makes more sense for your project. Often it helps to use both definitions—that is, you work primarily with the people involved with the next process step, but you check to ensure that their needs are consistent with the needs of the final customer. Keep in mind the following points:

   - The final customer, or end user, might be far removed from your particular job, but their needs are still important to you (and to everyone else in your organization).
   - You might have multiple customers (and thus multiple needs to consider).

  - If you work on administrative processes, your customers might include your suppliers. For example, a supervisor who supplies you with information that you incorporate into a report for him/her is your customer.

Tip As you work to identify your customers, check with your sponsor(s) and your marketing staff to see if there are large or influential customers whom you should make sure not to overlook.

Tip Often there is no single VOC. Different customers or types of customers usually have different needs and priorities. You should include a wide variety of customers in your initial customer-research efforts. Different types of customers are often referred to as *market segments*.

- Decide what you need to know about your customers.
  - Revisit your charter. What is the purpose of your project?
  - How does this purpose relate to the needs of the customers you have identified? What do you need to know about these customers' needs to make sure your project purpose is on track?

2. Collect and analyze reactive system data; then fill any gaps with proactive approaches.

- There are two types of data-collection systems: reactive and proactive.
- *Reactive* systems involve information that you receive whether or not you take any action to obtain it.
  - Reactive systems are customer-initiated. Some examples are complaints, returns, credits, and warranty claims.

  - It is best to start your data-collection process with reactive data because it is usually easier to get and can give you a basic understanding of customer concerns, allowing you to better focus your proactive work.

- Reactive systems generally gather data about the following:
  - Current and former customer issues or problems.
  - Current and former customers' unmet needs.
  - Current and former customers' interest in particular products or services.

Tip Sometimes customers communicate with you when they have a problem, but other times they let their behavior do the talking. Also, they often don't think of a problem they have as a problem that your organization can solve. Rather, they might blame themselves for the product or service not working right, think they have the wrong product or service, or simply take their business elsewhere. Reactive systems help you capture all the ways in which customers communicate their needs.

Tip It is important to explore this often-underused source of information before making an effort to gather new information. You can learn a great deal about improving your existing products and services if you put extra effort into categorizing and analyzing data from reactive systems and reviewing them periodically to identify patterns, trends, and other opportunities.

Tip Feedback from customers is easily lost. Extra effort must be made to preserve as much of this information as possible.

- *Proactive* systems involve taking action to gather information.
  - Proactive systems are not customer-initiated. Some examples are market research, customer interviews, and surveys.
  - Follow up on the information you obtain to expand your understanding of your customers' needs and to quantify the importance they place on various product/service characteristics.

Tip Proactive systems are those in which you initiate contact with customers. Ideally, they involve some face-to-face interviews or customer-site visits. Typically they also involve telephone interviews or surveys and/or questionnaires that customers fill out and return to your organization.

Tip You will likely have to design and initiate targeted customer contact to gather information specifically related to your project. Look for ways to integrate your efforts with ongoing customer contact done by your organization. For example, request that customer service or marketing staff ask additional questions during their regular contacts with customers, or see if your customers will allow you to observe their workplace during a scheduled visit.

3. **Analyze the data you collect to generate a key list of customer needs in their language. Much of this data will be verbal. It is helpful to summarize this information in a meaningful way, perhaps by using an Affinity Diagram.**

4. **Use an Affinity Diagram, a CTQ Tree, and the Kano Model to prioritize the CTQs for your project.**

y = f (x) Formula

Identifying the key process drivers

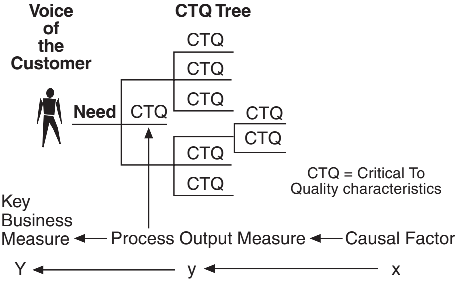
Why use it?

To determine what factors in your process (as indicated by a measure) you can change to improve the CTQs—and, ultimately, the key business measures.

What does it do?

- Illustrates the causal relationship among the key business measures (designated as Y), the process outputs directly affecting the Y's (designated as CTQ or y), and the factors directly affecting the process outputs (designated as x)
- Enables members of your improvement team to communicate the team's findings to others in a simple format
- Highlights the factors the team wants to change and what impact the change will have
- Provides a matrix that can be used in the Control step of the DMAIC method for ongoing monitoring of the process after the team's improvement work is complete

A Causal Relationship



Many people understand the concept of y = f (x) from mathematical education. The x, y, Y matrix is based on this concept. If it confuses team members to use these letters, simply use the terms *key business measures*, *CTQ* or *process outputs*, and *causal factors* instead; they represent the same concepts.

How do I do it?

1. **Gather the key business measures for your project (see the team charter or check with your sponsor)**

2. **Gather the CTQs that the improvement team selects as the most important for your project**

3. **List the key business measure and the CTQ operational definition in a matrix, like the one on the next page**

4. **As your team progresses through the Measure and Analyze steps of the DMAIC method, add the causal-factor definitions (x's) you discover**

   Tip When filling out the matrix , use the guidelines in the table shown on page 266 for assistance.

A Sample x, y, Y Matrix

	Y ←	y ←	x
Example 1	Revenue: Percentage of revenue from new accounts	Percentage of credit applications approved late	Elapsed time from receipt of all documentation to decision being made
Example 2	Expenses: Timeliness	Percentage of questions not resolved the first time	Percentage of questions not in “Frequently Asked Questions” guide Uptime on the computer system

Guidelines for Filling Out an x, y, Y Matrix

	Y ←	y ←	x
What Is Being Measured	Indicators of how the overall organization is performing and of where improvement and innovation need to take place.	Measures of primary interest to the customer or business; how a defect relates to the customer's CTQ measurements.	Measures of importance to the process and the workers, but of little direct importance to the customer.
How Used	Used to make strategic business decisions and to allocate resources.	Used to assess how well the process is performing, where improvement and innovation need to take place, and how the performance of this process relates to the Y's.	Used as tactical day-to-day levers to influence y and Y and to focus improvement teams as needed.
Timing	• Lagging indicator of y (i.e., you will see movement in the Y variable after the y variable has moved). • Note: Time lag might be short or long depending on your measurement system.	• Lagging indicator of x (i.e., you will see movement in the y variable after the x has moved). • Leading indicator of Y (i.e., you will see movement in the y variable before you see change in the Y). • Note: Time lag might be short or long depending on your measurement system.	• Leading indicator of y (i.e., you will see movement in the y variable after you see change in the x variable).
How Measured	Expressed as actual performance.	Can be expressed as a sigma score comparing a customer's or business's requirements to the actual performance.	Can be expressed as a sigma score comparing an in-process requirement to the actual performance.

GOAL QPC

Improving the Way Organizations Run

THE Lean Enterprise

MEMORY JOGGER™

Create Value
and
Eliminate Waste
throughout
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Company

Richard L. MacInnes
Net Results Inc.

First Edition

GOAL/QPC

The Lean Enterprise Memory Jogger™

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Printed in the United States of America

First Edition 10 9 8 7 6 5 4 3 2 1

ISBN 1-57681-045-3

Acknowledgments

Our sincere thanks to the people and organizations who reviewed draft versions of *The Lean Enterprise Memory Jogger*™ and offered suggestions and encouragement. Their participation in the development process assured us that the tools and methods described in this book are relevant and appropriate for all associates to use in their quest to achieve a truly lean enterprise.

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Foreword

In today's highly competitive market, there is an intense drive to ensure that an organization's operations are as productive as possible. The benefits that result from becoming a "lean" organization include the freeing up of capital, the reduction of inventory exposure during periods of slowdown, and the ability to qualify as a preferred supplier.

The tools and methods outlined in this book for optimizing resources, streamlining operations, and eliminating waste had their origins in manufacturing. Experience, however, has shown that these methods are applicable everywhere. For this reason, we have named this book *The Lean Enterprise Memory Jogger™*.

We believe this book will enable associates at all levels to quickly learn and begin applying the most commonly used tools for creating value and eliminating waste.

We wish you well.

Bob Page
Director, Product Development
GOAL/QPC

Table of Contents

Chapter 1
Introduction

What is a lean enterprise?

Many companies today are becoming lean enterprises by replacing their outdated mass-production systems with lean systems to improve quality, eliminate waste, and reduce delays and total costs.

A lean system emphasizes the prevention of waste: any extra time, labor, or material spent producing a product or service that doesn't add value to it. A lean system's unique tools, techniques, and methods can help your organization reduce costs, achieve just-in-time delivery, and shorten lead times.

A lean enterprise fosters a company culture in which all employees continually improve their skill levels and production processes. And because lean systems are customer focused and driven, a lean enterprise's products and services are created and delivered in the right amounts, to the right location, at the right time, and in the right condition. Products and services are produced only for a specific customer order rather than being added to an inventory.

A lean system allows production of a wide variety of products or services, efficient and rapid changeover among them as needed, efficient response to fluctuating demand, and increased quality.

How to use this book

This book will explain what you need to know to transform your organization into a lean enterprise. The specific information you will learn includes the following:

- Concepts and definitions you need to know
- Skills you need to develop
- Tools you need to use
- Steps you need to take

This information will help you and your team work together systematically toward your lean-enterprise goals.

What do the icons mean?

Topics of special interest to engineering staff or team leaders are marked with this icon. Operators may choose to skip these sections.

LEADER

TEAM

Topics that are best addressed by an entire team working together are marked with this icon.

Chapter 2

The Goals of the Lean Enterprise

Your organization can apply lean methods and techniques to your product-production and business processes to deliver better value to your customers. A lean initiative has four main goals:

Goal #1: Improve quality.

Quality is the ability of your products or services to conform to your customers' wants and needs (also known as expectations and requirements). Product and service quality is the primary way a company stays competitive in the marketplace.

Goal #2: Eliminate waste.

Waste is any activity that takes up time, resources, or space but does not add value to a product or service. An activity adds value when it transforms or shapes raw material or information to meet your customers' requirements. Some activities, such as moving materials during product production, are necessary but do not add value. A lean organization's primary goal is to deliver quality products and services the first time and every time. As a lean enterprise, you accomplish this by eliminating all activities that are waste and then targeting areas that are necessary but do not add value.

Goal #3: Reduce lead time.

Lead time is the total time it takes to complete a series of tasks within a process. Some examples are the period between the receipt of a sales order and the time the customer's payment is received, the time it takes to transform raw materials into finished goods, and the time it takes to introduce new products after they are first designed. By reducing lead time, a lean enterprise can quickly respond to changes in customer demand while improving its return on investment, or ROI (see Glossary).

Goal #4: Reduce total costs.

Total costs are the direct and indirect costs associated with production of a product or service. Your company must continually balance its products' and services' prices and its operating costs to succeed. When either its prices or its operating costs are too high, your company can lose market share or profits. To reduce its total costs, a lean enterprise must eliminate waste and reduce lead times.

Why are these goals important?

- Implementing lean tools and techniques will enable your company to meet its customers' demand for a quality product or service at the time they need it and for a price they are willing to pay.
- Lean production methods create business and manufacturing processes that are agile and efficient.
- Lean practices will help your company manage its total costs and provide a fair ROI to its stakeholders.

Goal #1: Improve Quality

Quality improvement begins with an understanding of your customers' expectations and requirements. Once you know what your customers want and need, you can then design processes that will enable you to provide quality products or services that will meet their expectations and requirements. In a lean enterprise, quality decisions are made every day by all employees.

How to do it

LEADER

1. Begin your quality-improvement activities by understanding your customers' expectations and requirements. Tools such as quality function deployment (see Glossary) are helpful ways to better understand what your customers want and need.

2. Review the characteristics of your service or product design to see if they meet your customers' wants and needs.

3. Review your processes and process metrics to see if they are capable of producing products or services that satisfy your customers.
4. Identify areas where errors can create defects in your products or services.
5. Conduct problem-solving activities to identify the root cause(s) of errors.
6. Apply error-proofing techniques to a process to prevent defects from occurring. You might need to change either your product/service or your production/business process to do this.
7. Establish performance metrics to evaluate your solution's effectiveness.

Goal #2: Eliminate Waste

To eliminate waste, begin by imagining a perfect operation in which the following conditions exist:

- Products or services are produced only to fill a customer order—not to be added to inventory.
- There is immediate response to customer needs.
- There are zero product defects and inventory.
- Delivery to the customer is instantaneous.

By imagining a perfect operation like this, you will begin to see how much waste there is hidden in your company. Using lean initiatives will enable you to eliminate waste and get closer to a perfect operation.

The seven types of waste

As you use the tools and techniques of lean production, you will work to eliminate seven types of waste, which are defined below:

- **Overproduction**. The worst type of waste, overproduction occurs when operations continue after they should have stopped. The results of overproduction are 1) products being produced in excess quantities and 2) products being made before your customers need them.
- **Waiting.** Also known as *queuing*, this term refers to the periods of inactivity in a downstream process that occur because an upstream activity does not deliver on time. Idle downstream resources are then often used in activities that either don't add value or, worse, result in overproduction.
- **Transport.** This is the unnecessary movement of materials, such as work-in-progress (WIP) materials being transported from one operation to another. Ideally, transport should be minimized for two reasons: 1) it adds time to the process during which no value-added activity is being performed, and 2) goods can be damaged during transport.
- **Extra Processing.** This term refers to extra operations, such as rework, reprocessing, handling, and storage, that occur because of defects, overproduction, and too much or too little inventory. Another example of extra processing is when an inside salesperson must obtain customer information that should have been obtained by

the outside salesperson handling the account. It is more efficient to complete a process correctly the first time instead of making time to do it over again to correct errors.

- **Inventory**. This refers to any excess inventory that is not directly required for your current customer orders. It includes excess raw materials, WIP, and finished goods. Keeping an inventory requires a company to find space to store it until the company finds customers to buy it. Excess inventory also includes marketing materials that are not mailed and repair parts that are never used.
- **Motion.** This term refers to the extra steps taken by employees and equipment to accommodate inefficient process layout, defects (see the section below), reprocessing, overproduction, and too little or too much inventory. Like transport, motion takes time and adds no value to your product or service. An example is an equipment operator's having to walk back and forth to retrieve materials that are not stored in the immediate work area.
- **Defects**. These are products or aspects of your service that do not conform to specification or to your customers' expectations, thus causing customer dissatisfaction. Defects have hidden costs, incurred by product returns, dispute resolution, and lost sales. Defects can occur in administrative processes when incorrect information is listed on a form.

Tip As you begin your lean initiative, concentrate first on overproduction, which is often a company's biggest area of waste. It can also hide other production-related waste. As your lean initiative progresses, your company will become able to use its assets for producing products or services to customer orders instead of to inventory.

How to do it LEADER

1. Begin your team-based waste-reduction activities by identifying a product or operation that is inefficient.
2. Identify associated processes that perform poorly or need performance improvement. If appropriate, select the operation in your organization with the lowest production output as a starting point for your waste-reduction activities.
3. Begin by creating a value stream map for the operation you are reviewing. (See chapter 3, “Mapping the Value Stream,” for details.)
4. Review the value stream map to identify the location, magnitude, and frequency of the seven types of waste associated with this operation.
5. Establish metrics for identifying the magnitude and frequency of waste associated with this operation. (See chapter 11, “Lean Metrics,” for details.)
6. Begin your problem-solving efforts by using lean principles to reduce or eliminate the waste.
7. Periodically review the metrics you have identified to continue eliminating waste associated with this operation.
8. Repeat this process with other inefficient operations in your organization.

Goal #3: Reduce Lead Time

Reducing *lead time*, the time needed to complete an activity from start to finish, is one of the most effective ways to reduce waste and lower total costs. Lead time can be broken down into three basic components:

1. **Cycle time.** This is the time it takes to complete the

tasks required for a single work process, such as producing a part or completing a sales order.

2. **Batch delay.** This is the time a service operation or product unit waits while other operations or units in the lot, or batch, are completed or processed. Examples are the period of time the first machined part in a batch must wait until the last part in the batch is machined, or the time the first sales order of the day must wait until all the sales orders for that day are completed and entered into the system.

3. **Process delay.** This is the time that batches must wait after one operation ends until the next one begins. Examples are the time a machined part is stored until it is used by the next operation, or the time a sales order waits until it is approved by the office manager.

As you think about places where you can reduce lead time in your product production or business process, consider the following areas:

- Engineering design and releases
- Order entry
- Production planning
- Purchasing
- Order fulfillment
- Receiving
- Production
- Inspection/rework
- Packaging
- Shipping
- Invoicing and payment collection

Below is a list of possible lead-time solutions to consider and their goals. They are divided into three categories: product design, manufacturing, and supply.

Product design

- Product rationalization. This involves simplifying your product line or range of services by reducing the number of features or variations in your products or services to align more directly with your customers' wants and needs.

Manufacturing

- Process simulations. These enable you to model your work processes to reveal waste and test the effects of proposed changes.
- Delayed product configuration. This means waiting until the end of your production cycle to configure or customize individual products.
- One-piece, or continuous, flow of products and information. This enables you to eliminate both batch and process delays.
- Technology (i.e., hardware and software) solutions. These enable you to reduce cycle time and eliminate errors.
- Quick changeover. This involves making product/service batch sizes as small as possible, enabling you to build to customer order.
- Work process standardization. This means identifying wasteful process steps and then standardizing "best practices" to eliminate them.

Supply

- Demand/supply–chain analysis. This reveals wasteful logistical practices both upstream and downstream in your demand/supply chain. It often reveals excess inventories being held by your customers, your organization, and/or your suppliers due to long manufacturing lead times that result in overproduction. Freight analysis sometimes reveals that overproduction occurs in an effort to obtain freight discounts. However, these discounts do not necessarily offset the costs of carrying excess inventory.

How to do it

The steps your improvement team must take to reduce lead time are similar to the ones you take to eliminate waste.

1. Begin your team-based lead-time-reduction activities by creating a value stream map for the business process you are targeting. (See chapter 3, "Mapping the Value Stream," for details.)
2. Calculate the time required for the value-added steps of the process.
3. Review the value stream map to identify where you can reduce lead time. Brainstorm ways to make the total lead time equal the time required for the value-added steps that you calculated in step 2.
4. Determine what constraints exist in the process and develop a plan to either eliminate them or manage them more efficiently.
5. Establish metrics to identify the location, duration, and frequency of lead times within the process. (See chapter 11, "Lean Metrics," for details.)
6. Once you have established a plan for improving the process, measure the improvement.
7. Repeat this process for other inefficient operations in your organization.

Goal #4: Reduce Total Costs

What is it?

For cost management to be successful, everyone in your organization must contribute to the effort. When you implement a process to reduce total costs, your goal is to spend money wisely to produce your company's products or services.

To minimize the cost of its operations, a lean enterprise must produce only to customer demand. It's a mistake to maximize the use of your production equipment only to create overproduction, which increases your company's storage needs and inventory costs.

Before you can identify opportunities to reduce costs, your team should have some understanding of the way that your company tracks and allocates costs and then uses this information to make business decisions.

A company cost structure usually includes variable and fixed costs, which are explained below:

- **Variable costs.** These are the costs of doing business. These costs increase as your company makes each additional product or delivers each additional service. In manufacturing operations, variable costs include the cost of raw materials.
- **Fixed costs**. These are the costs of being in business. These costs include product design, advertising, and overhead. They remain fairly constant, even when your company makes more products or delivers more services.

Cost-Reduction Methods

Use one or more of the methods listed on the next page to identify places to reduce the costs related to your company's current processes or products/services.

These methods are useful for analyzing and allocating costs during the new-product-design process.

- **Target Pricing**. This involves considering your costs, customers, and competition when determining how much to charge for your new product or service. It's important to remember that pricing has an impact on your sales volumes, and thus your production volumes. The rise and fall of production volumes impact both the variable and fixed costs of the product—and ultimately how profitable it will be for your company.
- **Target Costing.** This involves determining the cost at which a future product or service must be produced so that it can generate the desired profits. Target costing is broken down into three main components, which enables designers to break down cost factors by product or service, components, and internal and external operations.
- **Value Engineering.** This is a systematic examination of product cost factors, taking into account the target quality and reliability standards, as well as the price. Value engineering studies assign cost factors by taking into account what the product or service does to meet customer wants and needs. These studies also estimate the relative value of each function over the product's or service's life cycle.

The following techniques are useful for analyzing and improving the cost of your organization's operations.

- **Activity-based costing (ABC)**. ABC systems allocate direct and indirect (i.e, support) expenses—first to activities and processes, and then to products, services, and customers. For example, your company might want to know what percentage of its engineering and procurement costs should be allocated to product families to determine product-contribution margin. In addition, you can do indirect cost allocations for each customer account, which enables you to do a customer-profitability analysis.

- **Kaizen (i.e., continuous improvement) costing**. This focuses on cost-reduction activities (particularly waste reduction and lead-time reduction) in the production process of your company's existing products or services.
- **Cost maintenance**. This monitors how well your company's operations adhere to cost standards set by the engineering, operations, finance, or accounting departments after they conduct target-costing and kaizen-costing activities.

How to do it

1. Decide whether your cost-improvement efforts will begin with new or existing product lines.

2. If new products or services are the focus of your improvement efforts, techniques to consider using are target pricing, target costing, and value engineering.

3. If existing products or services are your focus, begin by reviewing your company's high-cost products and processes. Apply ABC, Kaizen costing, and cost maintenance to assist your cost-improvement initiatives.

   Tip If your product-production process is inherently costly, first consider applying the lean-manufacturing techniques identified in this book. Then focus your efforts on reducing total costs. This typically involves company-wide participation.

Chapter 3

Mapping the Value Stream

What is a value stream?

The term *value stream* refers to all the activities your company must do to design, order, produce, and deliver its products or services to customers. A value stream has three main parts:

- The flow of materials, from receipt from suppliers to delivery to customers.
- The transformation of raw materials into finished goods.
- The flow of information that supports and directs both the flow of materials and the transformation of raw materials into finished goods.

There are often several value streams operating within a company; value streams can also involve more than one company.

What is a value stream map, and what does it do?

A *value stream map* uses simple graphics or icons to show the sequence and movement of information, materials, and actions in your company's value stream.

It helps employees understand how the separate parts of their company's value stream combine to create products or services.

Why use it?

A value stream map is the first step your company should take in creating an overall lean-initiative plan. A lean initiative begins with agreement among employees on the current state of your organization. Developing a visual map of the value stream allows everyone to fully understand and agree on how value is produced and where waste occurs. Creating a value stream map also provides the following benefits:

- Highlighting the connections among activities and information and material flow that impact the lead time of your value stream.
- Helping employees understand your company's entire value stream rather than just a single function of it.
- Improving the decision-making process of all work teams by helping team members to understand and accept your company's current practices and future plans.
- Creating a common language and understanding among employees through the use of standard value-stream-mapping symbols.
- Allowing you to separate value-added activities (see Glossary) from non-value-added activities and then measure their lead time.
- Providing a way for employees to easily identify and eliminate areas of waste.

What areas should I focus on to create a value stream map?

To effectively create a value stream map for your company's manufacturing or business processes, you should focus on the following areas:

- The flow of information—from the receipt of a sales order or production data all the way through the engineering, production, control, purchasing, production, shipping, and accounting processes.

- *Production activities*, which are the physical tasks employees must perform to produce a product or deliver a service.
- *Material flow*, the physical movement of materials from receiving, through production, to the shipment or delivery of finished goods or services.
- *Customer value*, which is an aspect of a product or service for which a customer is willing to pay. (This is sometimes referred to as "value added.")
- A *push system*, where materials are automatically moved from one operation to the next, whether or not they are needed.
- A *pull system*, where materials are moved from one operation to the next based on a request from the next operation.
- Any waste involved in your business or manufacturing processes.
- *Takt time*, which is the total available work time per day (or shift) divided by customer-demand requirements per day (or shift). Takt time sets the pace of production to match the rate of customer demand.
- *Lead time*, which is the time it takes to complete an activity from start to finish.
- You also need to become familiar with four types of icons, described in detail later in this chapter:

    1. Production-flow icons

    2. Material-flow icons

    3. Information-flow icons

    4. Lean manufacturing icons

Tip If you work in a manufacturing organization, at the beginning of your lean manufacturing initiative you should make a value stream map at the plant level only. As your initiative progresses, you might decide to depict an entire system for multiple plants or for your entire company.

How do I create a value stream map?

To begin, all employees should map the value stream by themselves. Usually, each employee's map will be different from all the others. Then, by comparing maps and working together to reach a consensus, your work team can develop the most accurate map of the value stream possible.

1. Assemble paper, pencils, erasers, and a stopwatch for collecting data.

2. Select a product or service to map. Conduct a quick tour of the value stream to view the end-to-end material and information flows, making sure that you have identified all the component flows.

   Tip Don't work from memory. Observe the value stream in action. Interview each team member on every shift, if applicable. Verify your observations against documented procedures, routings, job aids, and memoranda.

   Tip Remember to record exactly what you see without making any judgments. Don't waste time debating the merits of an activity or its proper sequence; just record what is happening.

3. Identify a representative customer of the product or service under review. Once you have identified a typical customer, gather data about typical order quantities, delivery frequencies, and number of product or service variations. This information will

help you establish the takt time for the customer and the product.

4. Begin mapping the value stream, starting with customer requirements and going through the major production activities. The result is a current-state map of the value stream.

   Tip Begin mapping the value stream by drawing on Post-it® Notes, which can be easily rearranged while your team comes to a consensus, or use a pencil and eraser to draw and refine your map.

5. Add production-flow, material-flow, information-flow, and lean manufacturing icons (see pages 20–23 for details) to your value stream map.

   Tip During data collection, show whether information is communicated in real time or in batches. If it is communicated in batches, show the size of the batches, how often they are sent, and the *process delay* (see Glossary).

   Tip Identify every location where material is stored, sits idle, or is moved.

   Tip If your company uses a kanban production-control system (see chapter 9, "The Kanban System," for details), show the use of load-leveling boxes or individual kanban posts (mailboxes). Also show where the physical kanbans are used.

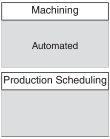
   Tip Identify all non-value-added activities in all the production, material, and information flows.

6. Create a lead-time chart at the bottom of your value stream map, showing the value-added and non-value-added production lead times.

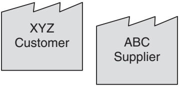
7. Review the map with all the employees who work in the value stream you have mapped to ensure you haven't missed any activities or materials.

Sample Production-Flow Icons

1. **Department or manufacturing process**. The top of the icon shows the name of the department or the process being mapped. The bottom of the icon shows resources, information, or a relevant lean-enterprise technique.



2. **Outside sources**. These include customers and suppliers. Try to use typical customers or suppliers for your mapping activities.

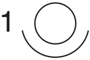


3. **Data box**. This is a place for key data such as machine availability; number of product variations that each operation typically produces; product changeover times; whether each part you produce can be run daily, weekly, or monthly; cycle time; process capacity; and first-time-through (FTT) quality levels (see Glossary). If the process you are mapping is machine based, record its overall equipment efficiency, or OEE, rate (see Glossary) and then identify which operation is the constraining operation.

C/T = 45 sec.
C/O = 30 min.
3 shifts
2% scrap

KPC = taste
KCC = temp.
Process stds.
Product specs

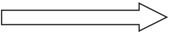
4. **People**. Shows the number of employees required to perform an operation. "Partial people" can be used; for example, "0.5" means that an employee spends half of his/her time performing a particular operation.



Sample Material-Flow Icons

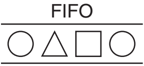
1. **Push movement of production materials**. Shows the movement of raw materials or components that are "pushed" by the production process rather than being requested by the customer.

2. **Pull movement of production materials**. Shows the movement of raw materials or components that are requested by the customer (i.e., they are not pushed).

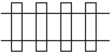


3. **Automated movement of production materials**. Indicates that automation is used to move raw materials or components from one process to another.

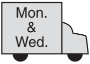
4. **FIFO**. Indicates that products need to be pulled and delivered on a first-in, first-out (FIFO) basis: the oldest remaining items in a batch are the first to move forward in the production process.



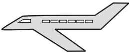
5. **Rail shipment**. Shows the movement of materials by train. Be sure to show the frequency of shipments on your map.



6. **Truck shipment**. Shows the movement of materials by truck. Be sure to show the frequency of shipments on your map.



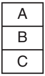
7. **Air shipment**. Shows the movement of materials by plane. Be sure to show the frequency of shipments on your map.



8. **Inventory**. Indicates the inventory count and time.

9. **Storage**. Shows all products contained in a storage area. You can note the minimum and maximum levels within each bin or row location.

10. **Emergency stock**. Shows all products contained in an emergency-stock area. You can note the minimum and maximum levels of each item.



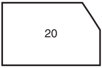
Sample Information-Flow Icons

1. **Manual information flow.** Shows information that is transferred by hand.

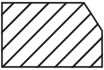
2. **Electronic information flow.** Shows information that is transferred via computer.

3. **Information type**. Indicates the type of information being communicated.

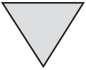
4. **Production kanban**. A card used to initiate the production of a certain item. (Used for kanban systems only; see chapter 9, “The Kanban System,” for details.)



5. **Withdrawal kanban**. A card used to obtain an item from a storage area. (Used for kanban systems only.)



6. **Signal kanban**. A card used to initiate a batch operation. (Used for kanban systems only.)

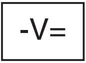


7. **Kanban card post**. This indicates the use of a physical mailbox location for kanbans. It is used for kanban systems only. (See chapter 9 for details.)

8. **Load leveling box**. Used for kanban systems to indicate load leveling (see Glossary). (See chapter 9 for details.)

Sample Lean Manufacturing Icons

1. **Visual management**. Shows that visual management techniques (see chapter 4, “Visual Management,” for details) have been applied.

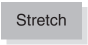


2. **Error proofing**. Shows that error-proofing techniques (see chapter 5, “Error-Proofing,” for details) have been applied.

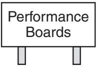
3. **Quick changeover**. Indicates that quick changeover techniques (see chapter 6, “Quick Changeover,” for details) have been applied.

4. **Product and process standards**. Shows that your company’s product and process standards are in place.

5. **Stretch objectives**. Shows where stretch objectives for fostering improvement have been set for specific operations or for the value stream as a whole.

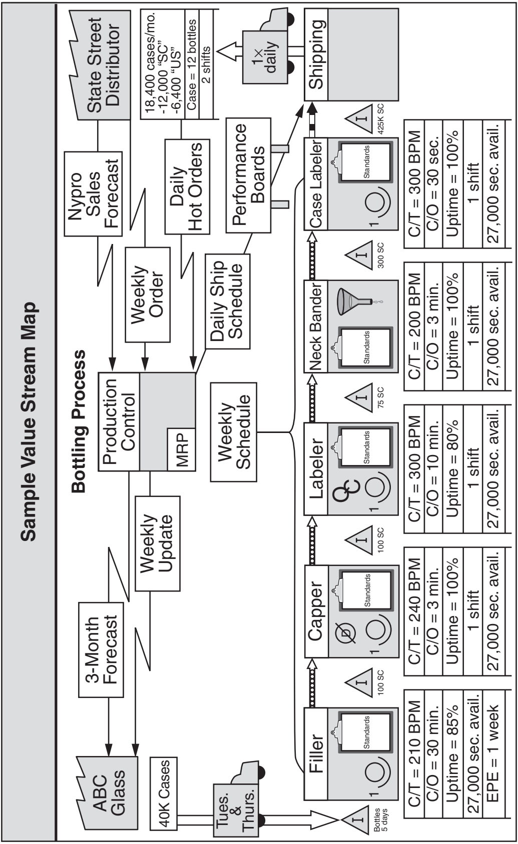


6. **Performance boards**. Indicates that process objectives and results have been posted in an operation’s work area.



7. **Constraining operation**. Shows which operation(s) constrains, or limits, the progress of the value stream.

A Sample Value Stream



How do I use my team's value stream map to make future improvements in my organization?

LEADER

After your team completes a map showing your organization's value stream in its current state, what's next? First, familiarize yourself with the lean methods and tools outlined in this book. Then consider the ideas below as you review your value stream map to plan future improvements for your organization.

Look at your takt time

- Your goal is to get your organization's value stream to produce to the takt time. You can calculate the takt time that your production or business processes must meet by using the following formula:

$$\text{takt time} = \frac{\text{available daily production time}}{\substack{\text{required daily quantity of output} \\ \text{(i.e., customer demand)}}}$$

When the value stream produces ahead of the takt time, overproduction occurs; when it produces behind the takt time, under-production occurs. If your value stream is not producing to the takt time, investigate possible causes. What processes might be negatively affecting production?

- Are you producing finished goods only to add them to inventory, or are your sales and operations activities integrated so that your production schedules are based on actual customer orders? Remember, your goal is to have your value stream driven by customer orders. It is also beneficial to minimize inventory in the production channel. This frees up your capacity, and you will then be able to meet smaller-order quantities more frequently.

Apply one-piece-flow principles

Does your value stream have large batch and process delays (see Glossary) that add to your lead time? Such delays can occur in your production, material, or information flows. To eliminate batch and process delays, try applying one-piece-flow principles to your value stream. (See chapter 8, "One-Piece Flow," for details.)

Apply quick-changeover, error-proofing, and visual management techniques

- Can you use quick-changeover methods to reduce your setup costs and batch sizes? (See chapter 6, "Quick Changeover," for details.) By reducing changeover times, your company will be able to run smaller batch sizes and free up production capacity. If being able to offer a mix of products and services is important, then quick changeover will reduce the number of operations you need to run every day, week, or month.
- Can you use error-proofing techniques to ensure that no product defects are being passed on to downstream operations? (See chapter 5, "Error Proofing," for details.) As batch sizes get smaller, the impact of product defects on your production schedules gets bigger. This is especially true if defects shut down operations.
- Have you conducted visual management activities, such as the 5 S's, in your important operational areas? (See chapter 4, "Visual Management," for details.) A well-organized and well-maintained workplace is key to ensuring that all employees perform their duties correctly and in a safe and proper manner, which ensures quality results.

Apply work-standardization techniques

Are your work standards displayed at each workstation? Are they easy to understand? Do they reflect current practices? Proper work instructions ensure that the correct decisions and physical tasks are being performed to meet lead-time, waste-reduction, and cost objectives.

Use load leveling

- Once you have applied one-piece-flow, quick-changeover, error-proofing, visual management, and work-standardization techniques, try using load leveling in your value stream. This prevents overproduction and under-production.

  For example, if one of your customers needs ten blues, twenty greens, and thirty yellows per five-day workweek, your objective is to build two blues, four greens, and six yellows each day. Then, if the customer decides to decrease or increase the order during the week, you can immediately respond by changing your production schedules to keep producing to the takt time.

- Check your build sequence. This can have a significant impact on your changeover times and product availability. Does your build sequence work well with your planned production volumes and mix? For example, it may be better to build two blues, then six yellows, and then four greens, rather than building four greens first. Eventually, you should develop a plan for every part of your build sequence that takes into account customer-service levels and production mix and volumes.

Establish lean metrics

Establish metrics for your value stream to make sure that you are meeting lead-time, waste-reduction, and cost objectives. Refer to chapter 11, “Lean Metrics,” for an introduction to core-process measures that you can apply to your organization’s value stream.

Use other tools to complement your value stream map

You can obtain excellent insight into your organization’s current and future operational practices by using a value stream map in conjunction with flowcharts (see *The Problem Solving Memory Jogger*™ for details) and a workflow diagram (see chapter 7, “Standard Operations,” for details).

Because the value stream map provides you with a “big picture” view of several interconnected activities, it is a good place to start. You can then further describe the details of specific work processes using flowcharting techniques.

A workflow diagram is useful for gathering physical information, such as the distance between work operations and the movement of employees and materials. It is possible to record such information on a value stream map, but it is more easily viewed and understood when you include it on a workflow diagram.

Chapter 4

Visual Management

What is it?

Visual management is a set of techniques that 1) expose waste so you can eliminate it and prevent it from recurring in the future, 2) make your company's operation standards known to all employees so they can easily follow them, and 3) improve workplace efficiency through organization. Implementing these techniques involves three steps:

- Organizing your workplace by using a method known as the 5 S's (sort, shine, set in order, standardize, and sustain); see page 32 for details.
- Ensuring that all your required work standards and related information are displayed in the workplace.
- Controlling all your workplace processes by exposing and stopping errors—and preventing them in the future.

What does it do?

Using visual management techniques enables your company to do the following:

1. Improve the "first-time-through" quality of your products or services by creating an environment that:
    - Prevents most errors and defects before they occur.
    - Detects the errors and defects that do occur and enables rapid response and correction.
    - Establishes and maintains standards for zero errors, defects, and waste.

2. Improve workplace safety and employee health by:
    - Removing hazards.
    - Improving communication by sharing information openly throughout the company.
    - Creating compliance with all work standards, reporting deviations, and responding quickly to problems.
3. Improve the overall efficiency of your workplace and equipment, enabling your organization to meet customer expectations.
4. Lower your total costs.

Why use it?

Creating an organized, efficient, cleaner workplace that has clear work processes and standards helps your company lower its costs. Also, employees' job satisfaction improves when their work environment makes it easier for them to get the job done right.

What areas should I focus on?

You can effectively gain control over your company's manufacturing or business processes by focusing on the following areas:

- Value-added activities. These are activities that change the form or function of your product or service.
- Information sharing. This is the distribution of the right information to the right people at the right time, in the most useful form possible.
- Source inspections. The goal of these inspections is to discover the source of errors that cause defects in either your products or business processes.

- Material quantities and flow. All work operations should result in the correct quantities of materials or process steps moving as required for downstream operations.
- Health and safety. All work processes, facilities, and equipment design and procedures should contribute to the maintenance of a safe and healthy workplace.

It is most effective to focus on the areas listed above as they relate to six aspects of your production or business processes:

1. The quality of incoming, in-process, and outgoing materials.
2. Work processes and methods of operation.
3. Equipment, machines, and tools.
4. Storage, inventory, and supplies.
5. Safety and safety training.
6. Information sharing.

Tip To gain control over your processes, you must understand the "three actuals":

- The actual place or location in which a process occurs.
- The actual employees working in that location.
- The actual process occurring in that location.

Mapping the process will help you understand all three actuals. (For details about mapping, see the "Set in order" section on page 34.)

Getting started

Before you begin to implement visual management techniques, make sure you do the following:

- Elect an employee from each work team to lead the program and remove any barriers his or her team encounters along the way.
- Train all involved employees about the visual management techniques outlined below.
- Tell everyone in the areas of your plant or office that will be involved about the program. Also give a "heads up" to other employees or departments that might be affected by it.
- Create storage ("red tag") areas for holding materials you will remove from work sites in your plant or building.
- Create a location for supplies you will need as you progress through your visual management program, such as tags, cleaning materials, paint, labels, marking tape, and sign materials.
- Coordinate the program with your maintenance department and any other departments that you might need to call on for help.
- Make sure that all employees understand and follow your company's safety regulations and procedures as they make changes.

How to do it

The 5 S's

1. **Sort.** Sort through the items in your work area, following the steps below. Your goal is to keep what is needed and remove everything else.
   a. Reduce the number of items in your immediate work area to just what you actually need.

b. Find appropriate locations for all these items, keeping in mind their size and weight, how frequently you use them, and how urgently you might need them.

c. Find another storage area for all supplies that you need but do not use every day.

d. Decide how you will prevent the accumulation of unnecessary items in the future.

e. Tape or tie red tags to all the items you remove from your work area. Place the items in a temporary "red-tag storage" area for five days. Either use the Sorting Criteria chart on page 38 as a guide for disposing of items or develop your own criteria.

f. After five days, move any item that you haven't needed to a central red-tag storage area for another thirty days. You can then sort through all items stored there to see if they might be of any use and throw away everything else, remembering to follow your company policy. Use a logbook to track what you do with all red-tag items.

Tip If employees disagree about what to do with some of the materials, try to resolve the conflict through discussion. They can also consult their managers about the materials' value, current and potential use, and impact on workplace performance.

2. **Shine**. Clean and "shine" your workplace by eliminating all forms of contamination, including dirt, dust, fluids, and other debris.

   Cleaning is also a good time to inspect your equipment to look for abnormal wear or conditions that might lead to equipment failure.

   Once your cleaning process is complete, find ways to eliminate all sources of contamination and to keep your workplace clean at all times.

Tip Keeping equipment clean and "shiny" should be a part of your maintenance process. Your company's equipment maintenance training should teach the concepts of "cleaning as inspection" and "eliminating sources of contamination."

Tip Remember that your workplace includes not just the plant floor, but your administrative, sales, purchasing, accounting, and engineering areas as well. You can clean these areas by archiving project drawings when they are completed and properly storing vendor catalogs and product information. Decide what methods (local or shared hard drives, floppy disks, or CDs) are the best for storing your electronic files.

3. **Set in order**. During this step, you evaluate and improve the efficiency of your current *workflow*, the steps and motions employees take to perform their work tasks. (See chapter 3, "Mapping the Value Stream.")

   a. Create a map of your workspace that shows where all the equipment and tools are currently located. Draw lines to show the steps that employees must take to perform their work tasks.

   b. Use the map to identify wasted motion or congestion caused by excessive distances traveled, unnecessary movement, and improper placement of tools and materials.

   c. Draw a map of a more efficient workspace, showing the rearrangement of every item that needs to be moved.

   d. On your map, create *location indicators* for each item. These are markers that show where and how much material should be kept in a specific place. Once you create your new workspace, you can hang up location indicators within it.

e. Make a plan for relocating items that need to be moved so you can make your new, efficient workspace a reality. (See the "Set in Order Work Sheet" below.) As you do this step, ask yourself the following questions:

- Who will approve the plan?
- Who will move the items?
- Are there any rules, policies, or regulations that affect the location of these items? Will employees be able to adhere to these rules?
- When is the best time to relocate these items?
- Do we need any special equipment to move the items?

Tip As a team, brainstorm your ideas for new ways to lay out your workspace. If it is impractical or impossible to move an item the way you would like, redesign the rest of the workspace around this item's location.

f. Post the drawing of the new workplace layout in your area.

Set in Order Work Sheet

Item to Relocate	Old Location	Proposed Location	Apprvd. by	Given to	Relocation Timing	Status

Date:
Dept.:
Prepared by:

4. **Standardize**. Make sure that team members from every work area follow the sort, shine, and set-in-order steps. Share information among teams so that there is no confusion or errors regarding:
    a. Locations
    b. Delivery
    c. Destinations
    d. Quantities
    e. Schedules
    f. Downtime
    g. Procedures and standards

As you begin to use your newly organized workplace, have everyone write down their ideas for reducing clutter, eliminating unnecessary items, organizing, making cleaning easier, establishing standard procedures, and making it easier for employees to follow the rules.

Once you have standardized your methods, make your standards known to everyone so that anything out of place or not in compliance with your procedure will be immediately noticed.

5. **Sustain.** The gains you make during the above four steps are sustained when:
    a. All employees are properly trained.
    b All employees use visual management techniques.
    c. All managers are committed to the program's success.
    d. The workplace is well ordered and adheres to the new procedures all your employees have agreed upon.
    e. Your new procedures become a habit for all employees.

Reevaluate your workspace using the Sustain Evaluation Form (see the figure below) as needed. Encourage and recognize the achievement of all work areas that are able to sustain their visual management efforts. This helps your company to maintain a cycle of continuous improvement.

Sustain Evaluation Form

Visual Management “Sustain” Evaluation		**Yes/ No**	**Comments**
Sort	• Are all items in the work area necessary? • Have unnecessary items been red-tagged? • Have red-tagged items been removed?	Yes	All moved to red-tag area
Shine	• Have all areas been cleaned? • Has a cleaning schedule been established?	Yes	Schedule set; training under way
Set in Order	• Is the location for every item in the work area defined? • Is every item in its defined location?		
Standardize	• Have standards been established? • Are standards posted? • Have company-wide standards been adopted in the area?		
Sustain	• Is the evaluation being completed on a regular basis? • Are all schedules, such as the cleaning schedule, being followed?		

Sorting Criteria

Frequency of Use	Action
Never (unneeded)	Throw away
Once a year	Place in storage
Less than once a month	Store in factory or office
Once a week	Store in general work area
Once a day or more	Carry or keep at workstation

Questions to Ask:

What is this item used for?
How often is it needed?
Is it needed in this location? Anywhere else?
How many are needed?
Who uses it?
How easy is it to replace?
What might happen if it were not available when it was needed?
How much space does it occupy?
Are there any other reasons why this item should be kept here?

Red Tag Information

Red tags typically contain the following information. You can adapt this list to best suit your company's needs.

Item
Name
Quantity
Identification (inventory control number)
Approximate value
Date item tagged and reason
Department, shift, operator
Disposal method
Red-tag holding area log-in date
Holding area removal disposal date
Authorized by: ________________

Chapter 5

Error Proofing

What is it?

Error proofing is a structured approach to ensuring quality all the way through your work processes. This approach enables you to improve your production or business processes to prevent specific errors—and, thus, defects—from occurring.

What does it do?

Error-proofing methods enable you to discover sources of errors through fact-based problem solving. The focus of error proofing is not on identifying and counting defects. Rather, it is on the elimination of their cause: one or more errors that occur somewhere in the production process. The distinction between an error and a defect is as follows:

- An *error* is any deviation from a specified manufacturing or business process. Errors cause defects in products or services.
- A *defect* is a part, product, or service that does not conform to specifications or a customer's expectations. Defects are caused by errors.

The goal of error proofing is to create an error-free production environment. It prevents defects by eliminating their root cause, which is the best way to produce high-quality products and services.

Why use it?

For your organization to be competitive in the marketplace, you must deliver high-quality products and services that exceed your customers' expectations. You cannot afford to produce defective products or services.

A lean enterprise strives for quality at the source. This means that any defects that occur during one operation in a manufacturing or business process should never be passed on to the next operation. This ensures that your customers will receive only defect-free products or services.

In a "fat" system, any defects that are found can simply be discarded while operations continue. These defects are later counted, and if their numbers are high enough, root-cause analysis (see Glossary) is done to prevent their recurrence. But in a lean enterprise, which concentrates on producing smaller batch sizes and producing to order versus adding to inventory, a single defect can significantly impact performance levels.

When a defect occurs in a lean enterprise, operations must stop while immediate action is taken to resolve the situation. Obviously, such pauses in operations can be costly if defects occur often. Therefore, it is important to prevent defects before they can occur.

What areas do I focus on?

Your organization can achieve zero errors by understanding and implementing the four elements of error proofing. These are as follows:

1. General inspection.

2. 100% inspection.

3. Error-proofing devices.

4. Immediate feedback.

Below is an in-depth look at each of these four elements.

Element #1: General inspection

The first, and most important, element of error proofing is inspection. There are three types of inspections that organizations commonly use.

1. Source inspections. Source inspections detect errors in a manufacturing process before a defect in the final part or product occurs. The goal of source inspections is to prevent the occurrence of defects by preventing the occurrence of errors.

   In addition to catching errors, source inspections provide feedback to employees before further processing takes place. Source inspections are often the most challenging element of error proofing to design and implement.

2. Judgment inspections. Often referred to as end-of the-line inspections, final inspections, or dock audits, these are inspections during which a quality inspector or operator compares a final product or part with a standard. If the product or part does not conform, it is rejected.

   This inspection method has two drawbacks. First, it might not prevent all defects from being shipped to customers. Second, it increases the delay between the time an error occurs and the time a resulting defect is discovered. This allows the production process to continue to make defective products and makes root-cause analysis difficult.

   Tip If you rely on judgment inspections, it's important to relay inspection results to all the earlier steps in your production process. This way, information about a defect is communicated to the point in the process at which the problem originated.

3. Informative inspections. Informative inspections provide timely information about a defect so that root-cause analysis can be done and the production process can be adjusted before significant numbers of defects are created.

   Typically, these inspections are done close enough to the time of the occurrence of the defect so that action can be taken to prevent further defects from occurring.

   There are two types of informative inspections. They are as follows:

   - **Successive inspections**. These inspections are performed after one operation in the production process is completed, by employees who perform the next operation in the process. Feedback can be provided as soon as any defects are detected (which is preferable) or simply tracked and reported later. It is always better to report defects immediately.
   - **Self-inspections**. Operators perform self-inspections at their own workstations. If an operator finds a defect in a product or part, he/she sets it aside and takes action to ensure that other defective products or parts are not passed on to the next operation. The root cause of the defect is then determined and corrected. Often this involves putting error-proofing measures and devices in place to prevent the problem from recurring.

Tip Industrial engineering studies have shown that human visual inspection is only about 85% effective. Similar inaccuracies happen when humans directly measure physical properties, such as pressure, temperature, time, and distance. Use electronic or mechanical inspection devices to achieve better accuracy.

Tip Operator self-inspection is the second most effective type of inspection. It is much more effective and timely than successive inspection. The number of errors detected depends on the diligence of the operator and the difficulty of detecting the defect.

Tip Wherever practical, empower operators to stop the production line whenever a defect is detected. This creates a sense of urgency that focuses employees' energy on prevention of the defect's recurrence. It also creates the need for effective source inspections and self-inspections.

Element #2: 100% inspection

The second element of error proofing is 100% inspection, the most effective type of inspection. During these inspections, a comparison of actual parts or products to standards is done 100% of the time at the potential source of an error. The goal is to achieve 100% real-time inspection of the potential process errors that lead to defects.

It is often physically impossible and too time-consuming to conduct 100% inspection of all products or parts for defects. To help you achieve zero defects, use low-cost error-proofing devices (see page 44) to perform 100% inspection of known sources of error. When an error is found, you should halt the process or alert an operator before a defect can be produced.

Tip Zero defects is an achievable goal! Many organizations have attained this level of error proofing. One of the largest barriers to achieving it is the belief that it can't be done. By changing this belief among your employees, you can make zero defects a reality in your organization.

Statistical process control (SPC) is the use of mathematics and statistical measurements to solve your organization's problems and build quality into your products and services. When used to monitor product characteristics, SPC is an effective technique for diagnosing process-performance problems and gathering information for improving your production process.

But because SPC relies on product sampling to provide both product and process characteristics, it can detect only those errors that occur in the sample that you analyze. It gives a reliable estimate of the number of total defects that are occurring, but it cannot prevent defects from happening, nor does it identify all the defective products that exist before they reach your customers.

Element #3: Error-proofing devices

The third element of error proofing is the use of error-proofing devices: physical devices that enhance or substitute for the human senses and improve both the cost and reliability of your organization's inspection activities.

You can use mechanical, electrical, pneumatic, or hydraulic devices to sense, signal, or prevent existing or potential error conditions and thus achieve 100% inspection of errors in a cost-effective manner.

Common error-proofing devices include the following:

- Guide pins of different sizes that physically capture or limit the movement of parts, tooling, or equipment during the production process.
- Limit switches, physical-contact sensors that show the presence and/or absence of products and machine components and their proper position.
- Counters, devices used to count the number of components, production of parts, and availability of components.

- Alarms that an operator activates when he/she detects an error.
- Checklists, which are written or graphical reminders of tasks, materials, events, and so on.

Such industrial sensing devices are the most versatile error-proofing tools available for work processes. Once such a device detects an unacceptable condition, it either warns the operator of the condition or automatically takes control of the function of the equipment, causing it to stop or correct itself. These warning and control steps, known as *regulatory functions*, are explained more below.

These sensing devices can detect object characteristics by using both contact and non-contact methods. Contact sensors include micro-switches and limit switches; non-contact methods include transmitting and reflecting photoelectric switches.

Setting functions describe specific attributes that sensing devices need to inspect. All of the four setting functions listed below are effective error-detection methods:

1. Contact methods involve inspecting for physical characteristics of an object, such as size, shape, or color, to determine if any abnormalities exist.

Example: A sensor receives a reflective signal (sparks) only when the flintwheel is installed correctly.

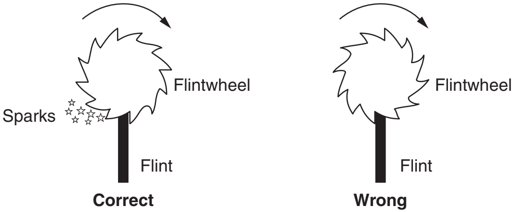


Figure courtesy of Allen Bradley

2. Fixed-value setting functions inspect for a specific number of items, events, and so on, to determine if any abnormalities exist. This technique is often used to ensure that the right quantity of parts has been used or the correct number of activities has been performed.

   Example: All materials must be used to assemble a case, including eight screws. A counter on the drill keeps track of the number of screws used. Another method is to package screws in groups of eight.

3. Motion-step setting functions inspect the sequence of actions to determine if they are done out of order.

   Example: Materials are loaded into a hopper in a predetermined sequence. If the scale does not indicate the correct weight for each incremental addition, a warning light comes on.

4. Information-setting functions check the accuracy of information and its movement over time and distance to determine if any gaps or errors exist.

   Here are some tips for using information-setting functions:

   - To capture information that will be needed later, use work logs, schedules, and action lists.

   - To distribute information accurately across distances, you can use e-mail, bar-coding systems, radio frequency devices, voice messaging systems, and integrated information systems, such as enterprise resource planning (ERP) (see Glossary).

   Example: Inventory placed in a temporary storage location must be accurately entered into the storeroom system for later retrieval during the picking operation. Bar-coding is used to identify part numbers and bin locations. This data is transferred directly from the bar-code reader to the storeroom system. Customers access the storeroom system through the internet.

Element #4: Immediate feedback

The fourth element of error proofing is immediate feedback. Because time is of the essence in lean operations, giving immediate feedback to employees who can resolve errors before defects occur is vital to success.

The ideal response to an error is to stop production and eliminate the source of the error. But this is not always possible, especially in continuous batch or flow operations. (See chapter 8 for details.) You should determine the most cost-effective scenario for stopping production in your work process when an error is detected.

It is often better to use a sensor or other error-proofing device to improve feedback time rather than relying on human intervention.

Methods for providing immediate feedback that use sensing devices are called *regulatory functions*. When a sensing device detects an error, it either warns an operator of the condition or makes adjustments to correct the error.

There are two types of regulatory functions. The first, the *warning method*, does not stop operations but provides various forms of feedback for the operator to act upon. Common feedback methods include flashing lights or unusual sounds designed to capture an operator's attention.

Example: A clogged meter sets off a warning light on a control panel. However, the operator can still run the mixer and produce bad powder.

The second type of regulatory function is called the *control method*. This method is preferred for responding to error conditions, especially where safety is a concern. However, it can also be a more frustrating method for the operator if a machine continually shuts itself down.

Example: A mixer will not operate until the water meter is repaired. The preventive maintenance program should have "meter visual inspections" on its schedule, and spare nozzles should be made available.

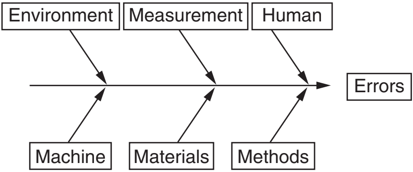
Warning methods are less effective than control methods because they rely on the operator's ability to recognize and correct the situation. If the operator does not notice or react to the error quickly enough, defective parts or products will still be produced. However, warning methods are preferred over control methods when the automatic shutdown of a line or piece of equipment is very expensive.

> ***Tip*** Don't let an error-proofing device sit idle! This happens all too often when people override sensors, disconnect them, or ignore them. If your employees are tempted to disconnect an error-proofing device, then install an error-proofing device for the error-proofing device.

What are some common sources of errors?

Common sources of error include humans, methods, measurements, materials, machines, and environmental conditions. These are examined in detail below.

Any one of these factors alone, or any combination of them, might be enough to cause errors, which can then lead to defects.



1. **Humans**. Unfortunately, human error is an unavoidable reality. The reasons are many. See the chart below for a list of reasons.

Reasons for Human Error

Lack of knowledge, skills, or ability. This happens when employees have not received proper training to perform a task and their skill or knowledge level is not verified.

Mental errors. These include slips and mistakes. *Slips* are subconscious actions. They usually occur when an experienced employee forgets to perform a task. *Mistakes* are conscious actions. They occur when an employee decides to perform a task in a way that results in an error.

Sensory overload. A person's ability to perceive, recognize, and respond to stimuli is dramatically affected by the sharpness of the five senses. When an employee's senses are bombarded by too many stimuli at once, sensory overload results, and his/her senses are dulled. This increases the chance for error.

Mechanical process errors. Some tasks are physically difficult to do and are thus prone to error. They can result in repetitive-strain injuries and physical exhaustion, which are both known to cause errors.

Distractions. There are two types of distractions: internal and external. External distractions include high-traffic areas, loud conversations, and ringing phones. Emotional stress and daydreaming are examples of internal distractions. Both types can lead to errors.

Loss of memory. Many work tasks require employees to recall information that can be forgotten. In addition, aging, drug or alcohol use, and fatigue can all cause memory loss and lead to errors.

Loss of emotional control. Anger, sorrow, jealousy, and fear often work as emotional blinders, hampering employees' ability to work effectively.

2. **Measurements**. Measurements must be accurate, repeatable, and reproducible if they are to successfully locate a problem. Unfortunately, measurement

devices and methods are as equally prone to error as the processes and products that they measure.

Inspection measurement practices, measurement graphs and reports, and measurement definitions are all potential sources of misinterpretation and disagreement. For instance, a measurement scale's being out of calibration can cause errors.

Tip Don't be surprised if a root-cause analysis points to measurement as the source of an error. An accurate measurement is the product of many factors, including humans, machines, and methods.

3. **Methods**. Industry experts believe that nearly 85% of the errors that occur in a work process are caused by the tasks and technology involved in the process. The sources of error in a work process are as follows:

   - **Process steps**. These are the physical or mental steps that convert raw materials into products, parts, or services.
   - **Transportation**. This refers to the movement of materials, information, people, and technology during a work process.
   - **Decision making**. This is the process of making a choice among alternatives. Make sure that all your employees' decisions address six basic questions: Who? What? When? Where? How? Why?
   - **Inspections**. These are activities that compare the actual to the expected. As noted above, they are prone to error.

Tip The area of work processes is the one where lean enterprises make the largest gains in error reduction and quality improvement. Concentrate your organizational efforts on this area.

4. **Materials**. This factor can contribute to error in the following ways:
    - Use of the wrong type or amount of raw materials or use of incompatible raw materials, components, or finished products.
    - Inherent product, tool, or equipment designs. A root-cause analysis typically leads back to faulty manufacturing, materials handling, or packaging practices.
    - Missing or ill-designed administrative tools (e.g., forms, documents, and office supplies) that do not support performance requirements.
5. **Machines**. Machine errors are classified as either predictable or unpredictable. Predictable errors are usually addressed in a preventative or scheduled maintenance plan (see Glossary). Unpredictable errors, which are caused by varying machine reliability, should be considered when your organization purchases equipment. If satisfactory machine reliability cannot be achieved, then you must plan other ways to prevent and catch machine-related errors.
6. **Environmental conditions**. Poor lighting, excessive heat or cold, and high noise levels all have a dramatic affect on human attention levels, energy levels, and reasoning ability.

In addition, unseen organizational influences—such as pressure to get a product shipped, internal competition among employees, and pressure to achieve higher wage levels—all affect quality and productivity.

> ***Tip*** Error-proofing devices and techniques can be used for some, but not all, sources of environmentally caused errors. Often an organization's operating and personnel policies must be revised to achieve a goal of zero defects.

How do I error-proof “red-flag” conditions?

The probability that errors will happen is high in certain types of situations. These so-called red-flag conditions include the following:

Red-Flag Conditions

Lack of an effective standard. *Standard operating procedures (SOPs)* are reliable instructions that describe the correct and most effective way to get a work process done. Without SOPs, employees cannot know the quality of the product or service they produce or know with certainty when an error has occurred. In addition, when there are no SOPs, or if the SOPs are complicated or hard to understand, variations can occur in the way a task is completed, resulting in errors.

Symmetry. This is when opposite sides of a part, tool, material, or fixture are, or seem to be, identical. The identical sides of a symmetrical object can be confused during an operation, resulting in errors.

Asymmetry. This is when opposite sides of a part, tool, material, or fixture are different in size, shape, or relative position. Slight differences are difficult to notice in asymmetrical parts, leading to confusion, delays, or errors.

Rapid repetition. This is when the same action or operation is performed quickly, over and over again. Rapidly repeating a task, whether manually or by machine, increases the opportunity for error.

High or extremely high volume. This refers to rapidly repeated tasks that have a very large output. Pressure to produce high volumes makes it difficult for an employee to follow the SOPs, increasing the opportunity for errors.

Poor environmental conditions. Dim lighting, poor ventilation, inadequate housekeeping, and too much traffic density or poorly directed traffic can cause errors. The presence of foreign materials (e.g., dirt or oils), over-handling, and excessive transportation can also result in errors or damaged products and parts.

Continued on the next page

Red-Flag Conditions (continued)

Adjustments. These include bringing parts, tooling, or fixtures into a correct relative position.

Tooling and tooling changes. These occur when any working part of a power-driven machine needs to be changed, either because of wear or breakage or to allow production of different parts or to different specifications.

Dimensions, specifications, and critical conditions. Dimensions are measurements used to determine the precise position or location for a part or product, including height, width, length, and depth. Specifications and critical conditions include temperature, pressure, speed, tension coordinates, number, and volume. Deviation from exact dimensions or variation from standards leads to errors.

Many or mixed parts. Some work processes involve a wide range of parts in varying quantities and mixes. Selecting the right part and the right quantity becomes more difficult when there are many of them or when they look similar.

Multiple steps. Most work processes involve many small operations or sub-steps that must be done, often in a preset, strict order. If an employee forgets a step, does the steps in an incorrect sequence, or mistakenly repeats a step, errors occur and defects result.

Infrequent production. This refers to an operation or task that is not done on a regular basis. Irregular or infrequent performance of a task leads to the increased likelihood that employees will forget the proper procedures or specifications for the task. The risk of error increases even more when these operations are complicated.

Tip Always use data as a basis for making adjustments in your work processes. Using subjective opinion or intuition to make adjustments can result in errors—and eventually defects.

Tip Any change in conditions can lead to errors that in turn lead to defects. For instance, wear or degradation of production equipment produces slow changes that occur without the operator's awareness and can lead to the production of defective parts.

How do I error-proof my production process?

An effective way of error-proofing your work processes is to use the 7-Step Problem-Solving Model, a systematic model for solving problems. You use this model to identify errors, create solutions, and prevent the errors from happening again.

During this process, inspections are performed and error-proofing devices are installed during Step 4, which involves developing a solution and action plan.

Since all production processes are affected by product and machine design, work methods, employees' skill levels, and supporting technology, you must consider these factors during your error-proofing activities. A snapshot of the 7-Step Model is shown below.

The 7-Step Problem-Solving Model

1. Describe the problem
2. Describe the current process
3. Identify the root cause(s)
4. Develop a solution and action plan
5. Implement the solution
6. Review and evaluate the results
7. Reflect and act on learnings

(Note: An in-depth discussion of the 7-Step Problem-Solving Model is beyond the scope of this book. For a complete description, please refer to *The Problem-Solving Memory Jogger*™.)

Chapter 6
Quick Changeover

What is it?

Quick changeover is a method of analyzing your organization's manufacturing processes and then reducing the materials, skilled resources, and time required for equipment setup, including the exchange of tools and dies.

What does it do?

Using the quick-changeover method helps your production teams reduce downtime by improving the setup process for new product launches and product changeovers, as well as improving associated maintenance activities. In addition, it allows your organization to cost-effectively implement small-batch production or one-piece flow. (See chapter 8, "One-Piece Flow," for details.)

Why use it?

There are many advantages to using the quick-changeover method. These include the following:

- Members of your team can respond to changes in product demand more quickly.
- Machine capacity is increased, which allows for greater production capacity.
- Manufacturing errors are reduced.
- Changeovers are made more safely.
- You can reduce your inventory (and its associated costs) because it is no longer needed for extended downtimes.

- Once you can make changeovers according to an established procedure, you can train additional operators to perform these tasks, which increases the flexibility of your organization.
- Lead times are shortened, improving your organization's competitive position in the marketplace.

What skills and concepts do I need to know?

Before you get started with the quick-changeover process, all members of your work team should become familiar with the following key skills and concepts:

- The difference between internal and external processes. *Internal processes* are activities that an equipment operator must perform while the production line is idle. *External processes* are activities that can be performed while the line is still running.
- How to create a matrix diagram and a check sheet. (See *The Memory Jogger™ II* for details.)
- The Plan-Do-Check-Act (PDCA) Cycle of systematic process improvement. (See *The Problem Solving Memory Jogger™* for details.)
- How to create a process flowchart. (See pages 36–44 of *The Problem Solving Memory Jogger™* for details.)
- How to build and use shadow boards (see Glossary). This technique enables you to organize and store your tools and equipment in the most effective manner possible.
- Error-proofing techniques. (See chapter 5, "Error Proofing," for details.)

How to do it

TEAM

You use the PDCA Cycle to make improvements to your setup and changeover processes. The specific steps involved in this procedure are outlined on the next several pages.

1. Evaluate your current processes. **(Plan)**

   a. Conduct an overview of your current production process to identify all equipment and processes that require downtime for changeover. Include all processes that require tooling replacement or new dies, patterns, molds, paints, test equipment, filtration media, and so on.

   b. Collect data using a check sheet for each process. Make sure the check sheet includes information about the following:

      - Duration of the changeover. This is the time it takes from the start of the changeover process to its completion, including preparation and cleanup.
      - The amount of production typically lost during the changeover, including number of units not produced, number of hours that operators are not engaged in productive activities, lost production time, and rework (measured in hours and units).
      - Process events that are *constraint operations*: these are operations that are long in duration or are critical to completing the manufacturing process.

   c. Create a matrix diagram (see the next page) to display this data for each production process (categories might include setup time, resources and materials required, and changeover time).

A Sample Matrix Diagram

Data-Collection Matrix Diagram

Information Collected By	Process Name/ No.	Setup Time	Resources/ Materials Required	Changeover Time

d. Select a process as your target for improvement. A good process to choose is one that has a long downtime, setup time, and/or changeover time; is a frequent source of error or safety concerns; or is critical to process output.

Tip A constraint operation that requires a changeover during your production operations is often a good first target to select. Choose no more than three targets to work on at one time.

2. Document all the current changeover activities for the process you have selected. **(Plan)**

   a. Make a checklist of all the parts and steps required in the current changeover, including the following:

      - Names
      - Specifications
      - Numeric values for all measurements and dimensions

  - Part numbers
  - Special settings

b. Identify any waste or problems associated with your current changeover activities.

c. Record the duration of each activity. See the sample data sheet below.

Quick-Changeover Data Sheet

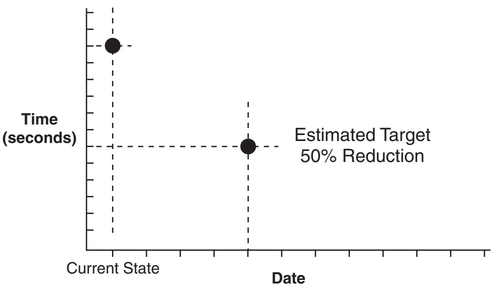
OP#: 20 Machine Shell | Team Members: Julie, Ben, Chris, Elise, Erik

Step #	Element	Time (minutes)	Elapsed Time (minutes)	Notes
10	Assemble cutting inserts	5	5	Inserts are not kitted to match the number of spindles. There are twelve spindles.
20	Move inserts to machine	10	15	Inserts kept in central store on other side of plant.
30	Remove old inserts	10	25	Old inserts must be logged in by spindle number.
40	Install inserts using sleeve positioner tool	30	55	Start new tool wear SPC chart.
50	Run twelve pieces for first piece inspection	5	60	Samples sent to quality for full dimensional check.

d. Create a graph of your current changeover time (in seconds) to establish a baseline for improvement.

e. Set your improvement target. A target of a 50% reduction is recommended.

Changeover Improvement Chart—Actual vs. Target

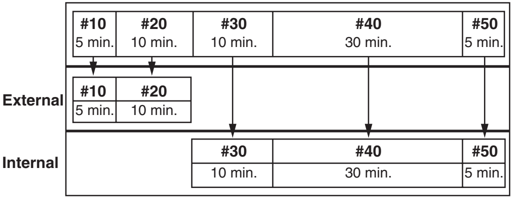


3. Identify internal and external process activities. **(Plan)**

   a. Create two categories on your checklist: one for internal processes, and one for external processes.

   b. List each task under the appropriate category, making sure to keep the tasks in the correct sequence.

Internal and External Process Activities



4. Turn as many internal processes as possible into external processes. **(Plan)**

   Using your checklist, complete the following steps:

   a. Identify the activities that employees currently perform while the line or process is idle that can be performed while it is still running.

   b. Identify ways to prepare in advance any operating conditions that must be in place while the line is running (e.g., preheating equipment).

   c. Standardize parts and tools that are required for the changeover process, including the following:

      - Dimensions.
      - Securing devices used.
      - Methods of locating and centering objects.
      - Methods of expelling and clamping objects.

5. Streamline the process. **(Plan)**

   a. Use visual management techniques (see chapter 4 for details) to organize your workplace.

   b. Consider ways to error-proof the process.

   c. Consider ways to eliminate unnecessary delays in your internal processes by doing the following:

      - Identifying the activities that can be done concurrently by multiple employees.
      - Using signals, such as buzzers or whistles, to cue operators.
      - Using one-turn, one-motion, or interlocking methods.

   d. Consider ways to eliminate unnecessary delays in your external processes by making improvements in the following:

      - Storage and transportation of parts and tools.

    - Automation methods.
    - Accessibility of resources.

   e. Create a new process map showing your proposed changes to the setup process.

6. Test your proposed changes to the process. **(Do)**

   a. Consider the feasibility of each proposed change.

   b. Prepare and check all materials and tools required for changeover. Make sure they are where they should be and that they are in good working order.

   c. Perform your revised setup activities for the parts and tools. Adjust settings, calibrate equipment, set checkpoints, and so on, as required.

   d. Perform a trial run of your proposed changes.

   e. Collect data on the duration of the setup time, and update your changeover improvement chart.

7. Evaluate the results of your changes. **(Check)**

   Take a look at the results of the changes you have made. Did the results meet your target goal? If so, go on to step 8. If not, make adjustments or consider other ways in which you can streamline your changeover activities and make the process external.

8. Implement your new quick-changeover process and continue to work to improve it. **(Act)**

   - Document the new procedures and train all involved employees on the new procedures.
   - Continue to collect data for continuous improvement of the changeover process.
   - Create a revised matrix diagram of the change processes (see step 1, item c) and begin the quick-changeover process again.

Chapter 7

Standard Operations

What are standard operations?

In a lean enterprise, a *work combination* is a mixture of people, processes, materials, and technology that comes together to enable the completion of a work process. The term *standard operations* refers to the most efficient work combination that a company can put together.

What do they do?

When you apply all your knowledge of lean principles to a particular work process to make it as efficient as possible, a standard operation is the result. Employees then use this documented process as a guide to consistently apply the tasks they must perform in that work process.

In addition, once you prepare standard operations for your work processes, they serve as the basis for all your organization's training, performance-monitoring, and continuous-improvement activities.

Why use them?

As discussed in previous chapters of this book, a big part of making your organization a lean enterprise is identifying different types of waste and finding ways to eliminate them. Ultimately, however, it is the correct combination of people, processes, materials, and technology that enables your organization to create quality products and services at the lowest possible operational cost.

Putting together standard operations forces you to break down each of your work processes into definable elements. This enables you to readily identify waste, develop solutions to problems, and provide all employees with guidance about the best way to get things done.

Many organizations that have used standard operations report that this lean initiative is the one that has had the biggest impact on their ability to produce better-quality products and services, make their work flow smoother, and make their training process more productive. In addition, standard operations enable employees to actually see the waste that they previously didn't see.

How do I develop standard operations for my organization?

The process for developing standard operations involves eight steps (listed below). A big part of this process involves gathering information about how your organization's work processes should be done.

1. Establish improvement teams.
2. Determine your takt time.
3. Determine your cycle time.
4. Determine your work sequence.
5. Determine the standard quantity of your work in progress.
6. Prepare a standard workflow diagram.
7. Prepare a standard operations sheet.
8. Continuously improve your standard operations.

The remainder of this chapter discusses these eight steps in detail.

Step 1: Establish improvement teams

Some organizations take a top-down approach to the development of standard operations: supervisors alone determine what work tasks are to be performed, by whom, and when. Other organizations believe that only front-line workers should develop standard operations because these employees have a keen insight into how things are done.

But due to the nature of the steps required to establish standard operations, a team-based approach is best. It is best to have all employees who are impacted by a work process involved in the development of standard operations for that process. Lean organizations understand the need for complete buy-in and support of all work tasks by all the employees involved. It's also important to coordinate this team effort with your organization's other lean initiatives.

Step 2: Determine your takt time

Takt time is the total available work time per day (or shift), divided by customer-demand requirements per day (or shift). Takt time enables your organization to balance the pace of its production outputs to match the rate of customer demand. The mathematical formula for determining your takt time is as follows:

$$\text{takt time} = \frac{\text{available daily production time}}{\text{required daily quantity of output}}$$

Step 3: Determine your cycle time

Cycle time is the time it takes to successfully complete the tasks required for a work process. It is important to note that a work process's cycle time may or may not equal its takt time.

The process capacity table is a helpful tool for gathering information about the sequence of operations that make up a work process and the time required to complete each operation. Ultimately, the process capacity table can help you determine machine and operator capacity.

Steps for Creating a Process Capacity Table

1. Enter the line/cell name.
2. Record the total work time per shift.
3. Enter the number of shifts.
4. Record the maximum output per shift.
5. Enter the sequence number of each processing step being performed on the part or product.
6. Record the *operation description*, which is the process being performed on the part or product.
7. Enter the number (if applicable) of the machine performing the process.
8. Record the *walk time*, the approximate time required between the end of one process and the beginning of the next process.
9. Enter the *manual time*, the time an operator must take to manually operate a machine when an automatic cycle is not activated. The manual time includes the time required to unload a finished part from the machine; load a new, unfinished part; and restart the machine.
10. Record the *automated time*, the time required for a machine's automatic cycle to perform an operation, from the point when the start button is activated to the point when the finished part is ready to be unloaded.
11. Calculate the *total cycle time* by adding the manual time and the automated time.
12. Enter the *pieces per change*, the total number of parts or products that a machine typically produces before its tool bits must be changed due to wear.
13. Record the *change time*, the amount of time required to physically change a machine's tool bits or perform a sample inspection. This is the time required to change tooling due to normal wear during a production run—not the changeover time required to go from making one part or product to making another.
14. Calculate the *time per piece*, the change time divided by the pieces per change.
15. Enter the *production capacity per shift* (also known as the total capacity). This is the total number of units that can be produced during the available hours per shift or per day.
16. Record the takt time for the work process in the Takt Time box, using the mathematical formula shown earlier in this chapter.
17. Calculate the *total capacity* of the process by adding the time to finish the process and the time per piece.

Process Capacity Table

Process Capacity Table						**Date:** 02/10	**Page** 1 **of** 1
Part No.	**Line/Cell Name**	**Total Work Time/Shift**	**# of Shifts**	**Maximum Output per Shift**	**Prepared by:** A. Thomas		
					Manager	**Supervisor**	**Team**
R45TS	Shell Mfg.	480 min.	1	27,000	R. Jones	S. Smith	Shell Team

Step	**Operation Description**	**Machine No.**	**Walk Time**	**Processing Time**			**Tool Change Time**				**Production Capacity per Shift**
				Manual	**Automated**	**Total Cycle**	**Pieces per Change**	**Change Time**	**Time per Piece**	**Takt Time**	
10	Cut Bar Stock	8125-B	5m		1s	1s	1	5m	5m		27,900
20	Machine Shell	8130-C	5m		5s	5s	10	60m	6m		36,000
30	Thread Shell	8199-A	5m		2s	2s	1	10m	10m		13,500
	Thread Shell	8198-C	5m		2s	2s	1	10m	10m		13,500
40	Weld Side Wire	8170-A	5m		1s	1s	1	5m	5m		27,900

Tip Complete a process capacity table *before* you begin making changes such as moving equipment, changing the sequence of your operations, or moving employees' positions and/or changing their job responsibilities. It is important to first know what your current capacity is and what it will be in the new process configuration that you plan.

Step 4: Determine your work sequence

A *work sequence* is the sequential order in which the tasks that make up a work process are performed. A work sequence provides employees with the correct order in which to perform their duties. This is especially important for multifunction operators who must perform tasks at various workstations within the takt time.

A standard operations combination chart enables your improvement team to study the work sequence for all your organization's work processes. In such a chart, each task is listed sequentially and broken down into manual, automated, wait, and walk times.

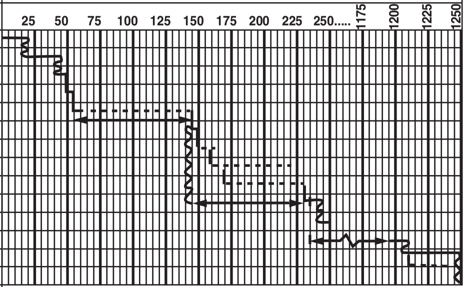
Wait time is not included in a process capacity table because worker idle time has no impact on automated activities or the capacity of a process. However, wait time is included in a standard operations combination chart to identify idle time during which a worker could instead be performing other tasks, such as external setup, materials handling, or inspection. The goal is to eliminate all worker idle time.

Standard Operations Combination Chart

Standard Operations Combination Chart					**Date:** 10/02	**Page** 1 **of** 1
					Operator: R. Smith	**Prepared by:** R. Smith
Item/Part No./ Name: Resistor Powder	**Process:** Mixing	**Machine:** Mixer Dryer Screener	**Cell:** Line 1	**Required Output:** 600#/shift **Cycle Time:** 1250	**Takt Time:** 240 min. **Gap:** 1010 min.	**Manual:** — **Auto:** - - - **Walk:** 〰 **Wait:** ↔

Step	Operation Description	Time			
		Manual	**Auto**	**Walk**	**Wait**
1	Retrieve raw materials	15		5	
2	Weigh materials	20			
3	Position materials	5		5	
4	Load materials	5			
5	Mix materials		90		90
6	Verify consistency	5			
7	Convey materials to dryer		10		
8	Dry powder		60		60
9	Screen powder		60		10
10	Load drums	5			
11	Dispose of unacceptable material	5		10	
12	Test Materials	30	30	25	990
	Totals	90	250	45	1050

Operation Cycle Time



The steps for completing a standard operations combination chart are described below.

1. At the top of a form like the one shown on page 69, indicate the following:
   a. The date that the work process is being mapped.
   b. The number of pages (if the chart is more than one page long).
   c. The name of the equipment operator.
   d. The name of the person entering data on the form (if different from the operator).
   e. The number and/or name of the part or product being produced.
   f. The name of the process or activity being mapped.
   g. The machine number and/or name.
   h. The work cell number and/or name.
   i. The required output per designated period (e.g., parts per shift or pounds per day).
   j. The takt time for the process.
   k. The total capacity for the process (see step 3). Ideally, this should equal the takt time that you calculated in step 2.
2. The difference between the takt time and the cycle time (see step 3) for the work process.
3. It is often helpful to indicate the type of units the work activity is usually measured in. Activities are normally measured in seconds, but some are measured in minutes or even longer intervals.
4. Number every fifth or tenth line on the graph area to facilitate your recording of activity times. Choose convenient time intervals so that either the takt time or the actual cycle time—whichever is greater—

is located near the right side of the graph area.

5. Draw a line that represents the activity's takt time. Trace the line with red so it stands out.
6. Sequentially number each operational step in the appropriate column. Steps can include any or all of the following:
   a. Manual operations.
   b. Automated operations.
   c. Time spent walking from one location to another.
   d. Time spent waiting.
7. Provide a brief name and description for each step.
8. Note the time required for the completion of each step in the appropriate column.
9. Draw a horizontal line on the graph representing each step, using the following guidelines:
   a. The length of the line should equal the duration of the step.
   b. The line type should match the action type (see the line key at the top of the sample chart).
   c. Each line type should be in a different color, which will make your chart much easier to read.
   d. Each line you draw should begin at the point on the vertical time line that corresponds to the actual time the activity begins. It should end at the actual time the activity ends.

For example, if the first step of a work activity is an automatic hopper fill that takes fifteen seconds to complete, and the operator assembles a carton for ten seconds during that fifteen seconds, both steps would start at time zero, with the carton assembly ending at time ten and the automatic fill ending at time fifteen.

However, if the operator waits until the automatic hopper fill is completed before assembling the carton, the fill would start at time zero and end at time ten, but the carton assembly would start at time fifteen and end at time twenty-five.

Your completed standard operations combination chart should provide you with some useful insights, including the following:

- If the total time to complete the process or activity equals the red takt-time line, congratulations! You already have an efficient work combination in place.
- If the total time required to complete the process or activity falls short of the red takt-time line, you might be able to add other operations to the activity to use your resources more effectively.
- If the total time required to complete the process or activity is longer than the red takt-time line, there is waste in your process.

Use the following steps to identify where this waste occurs:

1. Look over the steps in your process to see if any of them can be compressed or eliminated. Perhaps one or more steps can be completed during periods when the equipment operator is waiting for automated operations to be completed.

2. Look at the movement of employees and materials. Can you reduce or eliminate any of it by relocating supplies or equipment?

Step 5: Determine the standard quantity of your work in progress

The standard quantity of your work in progress (WIP) is the minimum amount of WIP inventory that must be held at or between your work processes. Without having this quantity of completed work on hand, it is impossible to synchronize your work operations.

When determining the best standard quantity of WIP you should have, consider the following points:

- Try to keep the quantity as small as possible.
- Ensure that the quantity you choose is suitable to cover the time required for your error-proofing and quality-assurance activities.
- Make sure that the quantity enables all employees to easily and safely handle parts and materials between work operations.

For more information on establishing inventory levels, see chapter 9, "The Kanban System."

Step 6: Prepare a standard workflow diagram

A *workflow diagram* shows your organization's current equipment layout and the movement of materials and workers during work processes. Such a diagram helps your improvement team plan future improvements to your organization, such as one-piece flow (see chapter 8, "One-Piece Flow," for details).

The information in your workflow diagram supplements the information in your process capacity table and standard operations combination chart. When combined, the data in these three charts serves as a good basis for developing your standard operations sheet (see step 7).

The steps for completing a workflow diagram are described below.

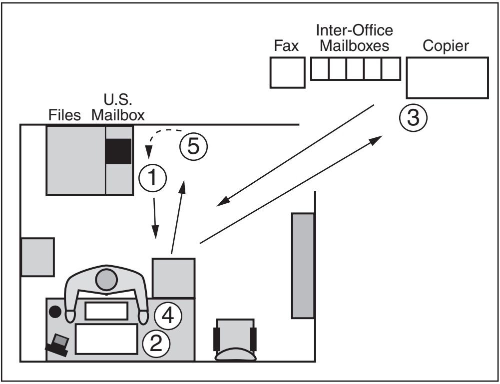
Workflow Diagram Steps

1. At the top of the diagram, indicate the following:
   a. The beginning and end points of the activity you are mapping.
   b. The date the activity is being mapped. The name of the person completing the diagram should also be included.
   c. The name and/or number of the part or product being produced.
2. Sketch the work location for the work process you are mapping, showing all of the facilities directly involved with the process.
3. Indicate the work sequence by numbering the facilities in the order in which they are used during the activity.
4. Connect the facility numbers with solid arrows and number them, starting with 1 and continuing to the highest number needed. Use solid arrows to indicate the direction of the workflow.
5. Using a dashed arrow, connect the highest-numbered facility to facility number 1. This arrow indicates a return to the beginning of the production cycle.
6. Place a diamond symbol (✧) at each facility that requires a quality check.
7. Place a cross symbol (†) at each facility where safety precautions or checks are required. Pay particular attention to facilities that include rotating parts, blades, or pinch points.
8. Place an asterisk (*) at each location where it is normal to accumulate standard WIP inventory. Adjacent to the asterisk, indicate the magnitude of the inventory—measured in number, weight, volume, and so on.
9. Also enter the total magnitude of the inventory in the “Number of WIP Pieces” box.
10. Enter the takt time for the operation in the “Takt Time” box. Calculate the takt time using the mathematical formula shown in “Step 2: Determine your takt time” earlier in this chapter.
11. Enter the time required to complete a single cycle of the activity in the “Cycle Time” box. Ideally, this time should equal the takt time.

The workflow diagram provides a visual map of workspace organization, movement of materials and workers, and distances traveled—information not included in either the process capacity table or the standard operations combination chart. You can use this information to improve your workspace organization, re-sequence your work steps, and reposition your equipment, materials, and workers to shorten your cycle time and the overall travel distance. This will help you to achieve your takt time.

Standard Workflow Diagram

Operation Sequence	From: Receipt of Sales Order	Date: February 28
	To: Release of Manufacturing Order	Part Name: Widget



Quality Check	Safety Precaution	No. of WIP Pieces	Process Delays	Takt Time	Cycle Time
			1–5 days		1–4 hours

Step 7: Prepare a standard operations sheet

Numerous formats exist for standard operations sheets. In general, the layout for your sheet should include the components listed below:

- The header section should contain the following:
  - Process name
  - Part or product name
  - Takt time
  - Cycle time
  - Sign-offs
  - Approval date
  - Revision level
- The work sequence section should contain the following:
  - Sequence number
  - Description of task
  - Manual time
  - Automated time
  - Walk time
  - Inventory requirements
  - Key points
  - Safety precautions
  - Related job procedures
- The workflow diagram section should contain a pictorial representation of the work area. (Refer to the workflow diagram discussion in step 6 for details.)

- The footer section should contain the following:
  - Lean enterprise tools applied to the work process
  - Safety equipment required
  - Page indicator (for multiple-page standard operations sheets)

The layout of a standard operations sheet is straightforward. See the sample below.

<table>
<tr><th colspan="6">Standard Operations Sheet</th></tr>
<tr><td colspan="5">Header:</td><td>Workflow Diagram</td></tr>
<tr><td colspan="5">Work Sequence
Information gathered from process capacity table and standard operations combination chart:</td><td rowspan="10"></td></tr>
<tr><td>#</td><td>Description</td><td>Time</td><td>Inventory</td><td>Safety/ Other</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Footer:</td></tr>
</table>

Step 8: Continuously improve your standard operations

After you complete your standard operations sheet, you should train all employees who are affected by your changes to the work process in question. Don't be surprised if, during this training, employees discover potential opportunities for even greater improvement.

It is through the continuous improvement of your standard operations that your organization can systematically drive out waste and reduce costs. You should review your organization's standard operations sheet(s) on a periodic basis to ensure all employees are accurately complying with them.

Chapter 8

One-Piece Flow

What is it?

One-piece flow is the movement of products through the manufacturing process one unit at a time. This is in contrast to batch processing (also known as large-lot processing), which produces a large number of identical units at once and sends all of them to each operation in the production process together.

What does it do?

One-piece flow focuses employees' efforts on the manufacturing process itself rather than on waiting, transporting products, and storing inventory. It also makes the production process flow smoothly, one piece at a time, creating a steady workload for all employees involved.

Why use it?

There are many advantages to incorporating the one-piece-flow method into your work processes. These include the following:

- It reduces the time that elapses between a customer order and shipment of the finished product.
- It prevents the wait times and production delays that can occur during batch processing.
- By reducing excess inventory, one-piece flow reduces the labor, energy, and space that employees must devote to storing and transporting large lots or batches.

- It reduces the damage that can occur to product units during batch processing.
- It reveals any defects or problems in product units early in the production process.
- It gives your organization the flexibility to meet customer demands for a specific product at a specific time.
- It reduces your operating costs by making non-value-added work more evident. This enables you to eliminate waste.

What are the requirements for using the one-piece-flow method?

One-piece flow works best when your production process and products meet certain requirements. One is that your product changeover times must be very short; almost instantaneous is best. One-piece flow is impractical when many time-consuming changeover operations are needed during the production process.

Another requirement is that the products you make must be suitable for one-piece flow. Very small product units are usually not suitable because too much time is required for their setup, positioning, and removal from production equipment.

One-piece flow might be possible for the production of very small product units if you can completely automate their movement through your production process and if your cycle time (see Glossary) is short.

Case example: Quick-Lite implements one-piece flow

Quick-Lite is a hypothetical company that produces spark plugs. One of the spark-plug components that Quick-Lite produces is the shell, which is the threaded part of the spark plug that is screwed into the engine.

Manufacturing a spark-plug shell involves four basic operations, as shown in the table below.

Operation	Cycle Time (seconds)
10 – Cut bar stock	1
20 – Machine shell	5
30 – Cut threads	2
40 – Weld side wire	1

Each of these four operations in Quick-Lite's batch process handles 1000 spark-plug shells before placing them into storage to wait for the next operation. The shells are stored for one hour after each operation.

The time required for Quick-Lite to manufacture 1000 spark-plug shells during its batch-processing method is calculated as follows:

Batch-Processing Method Calculation			
Operation	**No. of Pieces**	**Cycle Time (seconds)**	**Total Time (seconds)**
10	1000	1	1000
Storage delay			3600
20	1000	5	5000
Storage delay			3600
30	1000	2	2000
Storage delay			3600
40	1000	1	1000
		Total Time (seconds):	19,800

In a one-piece-flow method, as soon as one piece is finished, it is immediately moved and processed by the next operation. In such a manufacturing process, the constraining operation (see Glossary) is the one that limits the output rate of finished parts. In this case, the constraining operation is Operation 20.

Bar stock is cut (Operation 10) one second before it is required by Operation 20. Operation 30 begins only after the completion of Operation 20. Therefore, the lead time (see Glossary) for the first unit is nine seconds. Each subsequent unit comes off the production line every five seconds. Because all storage delays are eliminated, the total time to produce units 2 through 1000 is 4995 seconds.

Thus, the time required for Quick-Lite to manufacture 1000 spark plugs with a one-piece-flow method is just 5004 seconds (4995 + 9), compared to the 19,800 seconds required with a batch-processing method.

Using one-piece flow enables Quick-Lite to reduce its overall production time by about 75%. Real-world manufacturing operations that convert to the one-piece-flow method often show similar results.

How do I coordinate my production cycle time with my customer orders?

The number of units you produce should equal the number of items your customers order. In other words, your selling cycle time should equal your manufacturing cycle time.

Case example: Quick-Lite coordinates its cycle time with customer orders

Quick-Lite's customer, an automobile manufacturer, places an order for 9600 spark plugs to be delivered every day. The one-piece-flow production line is available for 16 hours (57,600 seconds) each day. Quick-Lite can fill the order by producing one spark-plug shell every six seconds (57,600 ÷ 9600 = 6).

Since the line is capable of producing one shell every five seconds, Quick-Lite can fill the order in 48,000 seconds (5 × 9600 = 48,000), leaving 9000 seconds (150 minutes) for other activities, such as shift changeover, total productive maintenance (see chapter 10 for details), and individual or team improvement.

Tip Don't be tempted to overproduce. Some companies produce extra quantities of their products in an effort to maximize the use of their machines. Before you decide to produce surplus inventory, first consider the costs of overproduction and maintaining an inventory.

What is the difference between a push system and a pull system?

"Fat" organizations use a *push system*. In such a system, goods are produced and handed off to a downstream process, where they are stored until needed. This type of system creates excess inventory.

Lean organizations, on the other hand, use a *pull system*, in which goods are built only when a downstream process requests them. The customer then "pulls" the product from the organization.

The final operation in a production process drives a pull system. Customer-order information goes only to the product's final assembly area. As a result, nothing is produced until it is needed or wanted downstream, so the organization produces only what is needed.

A pull system streamlines the flow of materials through your production process. This greatly improves your organization's productivity by doing the following:

- It reduces the time that employees spend in non-value-added steps, such as waiting and transporting product units.

- It reduces downtime caused by product changeovers and equipment adjustments.
- It reduces the distances that materials or works in progress must travel between assembly steps.
- It eliminates the need for inspection or reworking of materials.
- It bases your equipment usage on your cycle time.

Case example: Quick-Lite deals with over-capacity

One of Quick-Lite's threading machines can thread twelve spark-plug shells at a time. Quick-Lite purchased this machine several years ago to increase throughput.

When shell types are changed, twelve spindles must be set up on this machine. Once set up, it can produce twelve threaded shells every two seconds. But because Quick-Lite's customer requires only one threaded shell every six seconds, this machine creates an over-capacity that does not improve operations; it just builds up excess inventory.

Case example: Quick-Lite deals with under-capacity

If Quick-Lite has only one eight-hour shift (28,000 seconds) to produce all 9600 spark plugs it needs to deliver each day, it must produce shells at a rate of one every three seconds (28,000 ÷ 9600 = 3) to fill the order. But the company's current operations can produce at a rate of only one shell every five seconds. How can Quick-Lite fill this order in one shift?

Answer: Only one of the four operations in the process doesn't meet the three-second requirement: Operation 20, the constraining operation. To fill this order in one shift, Quick-Lite can either add additional capacity to this operation or, if possible, speed up the operation or break it up into multiple operations.

What is the best type of equipment for one-piece flow?

LEADER

To accommodate one-piece flow, equipment should be correctly sized to meet customer demand. Machines designed for batch production might not be easy to adapt to one-piece-flow cycle times.

One-piece flow works best with machines that are smaller and somewhat slower than equipment that is suited for batch processing. Equipment used for one-piece flow also needs to be easy to set up quickly so that you can use it to produce a wide mix of products.

Because the volume, capacity, and force requirements are often lower for one-piece-flow production, machines that are suited for it can be smaller. Smaller machines save space and leave little opportunity for waste, such as inventory and defective parts, to accumulate. They are also less expensive to purchase.

Slower machines are often sufficient for one-piece flow because the aim is to produce goods according to the manufacturing cycle time.

Automated and semi-automated machines work well in one-piece-flow production. They stop and give the operator a signal when a cycle is complete or if any problems occur. They are sometimes also capable of notifying the next operation when to begin processing. And they often unload automatically after processing is done.

> ***Tip*** Synchronize your equipment's production operations by delaying the start of faster operations rather than speeding up or slowing down the machines. Running production equipment outside of its specified range can reduce product quality or tool life.

Case example: Quick-Lite chooses appropriate machines

To fill Quick-Lite's order, Operation 30 needs to perform at a cycle time equal to that of Operation 20: one part every five seconds. But the throughput of Operation 30's multi-spindle machine is twelve parts every two seconds.

To implement one-piece-flow, Quick-Lite must synchronize the equipment used for Operations 20 and 30 to produce at the customer takt time.

Rather than using the multi-spindle machine, the team at Quick-Lite decides to use a smaller in-line threading machine that operates at a cycle time of one part every five seconds. This allows them to avoid extra setup time and overproduction.

The Quick-Lite team also decides that automating their machinery will work well because each operation in the production process has a different cycle time. Thus, when Operation 20, shell machining, is at the four-second mark, it signals Operation 10, bar-stock cutting, to perform its task.

How do I prepare my work areas and employee training for one-piece flow?

To achieve a one-piece-flow method's full potential, it is important to follow five points with regard to your work-cell layout and employee training. These points are outlined below.

1. Simplify the flow of your materials and parts. Below are several guidelines to follow:
   - Keep all goods flowing in the same direction.
   - Make sure all parts flow from storage through the factory according to the processing sequence.

- Use first-in, first-out, or FIFO (see Glossary), stocking.
- Arrange parts for easy feeding into the production line.
- Eliminate any non-value-added space in your work cells.
- Keep all pathways in work areas clear; leave aisles open along walls and windows.
- Make sure that material input and production output are separate operations.
- Position your equipment to allow easy maintenance access.
- Make sure separate work processes are located as close together as possible.

2. Set up your production lines to maximize the equipment operators' productivity. Review the feasibility of both straight-line and U-shaped work cells and their impact on both operator movement and productivity and the flow of work materials.

   Remember that a U-shaped work cell brings the ending point of a work process close to the beginning point, which minimizes the distance an operator has to move before beginning a new production cycle. This setup is better for some work processes than a straight-line work cell.

3. Allot space in the layout of your work cells for regular equipment and product inspection. Remember that the employees working in each cell must be able to easily conduct a full-lot inspection. Such inspections prevent defects by catching any errors and non-standard conditions. This ensures that only defect-free parts are fed to the next step in your production process.

4. Minimize your in-process inventory. Predetermine the stock that employees will have on hand for the entire production line. Arrange your work cells to enable an easy flow of materials into and out of all work areas.

5. When your equipment is arranged to enable a smooth process flow, equipment operators might need to learn how to run different types of equipment. Such operators usually need to work standing up, instead of sitting down, so they can easily run a number of machines in sequence. Keep this in mind when designing your work cells.

   Cross-train your employees so that they know how to perform different work functions. Equipment operators are then able to go to other work cells if production is not required at their normal work areas. This also enables an entire work team to take full responsibility for the production process.

What tools should I be familiar with to implement a one-piece-flow process?

Three tools are necessary for assessing and planning for a one-piece-flow process:

1. PQ analysis table
2. Process route table
3. Workflow diagram

These tools are explained below.

PQ analysis table

A *PQ analysis table* is a tool that helps employees understand the types of products your organization produces and the volume that your customers demand. It also shows whether the majority of your production volume is made up of a small or wide variety of parts.

The PQ analysis table enables employees to identify what products are suitable for one-piece-flow production. (The *P* in *PQ* stands for *products*; the *Q* stands for *quantity* of production output.)

Case example: Quick-Lite's PQ analysis

Quick-Lite conducts a PQ analysis of its spark-plug final-assembly part numbers to see if a wide or limited variety of spark plugs makes up most of the volume. They find that six spark plugs made up 53.3% of the total volume. The manufacturing processes for these six spark plugs are likely candidates for one-piece-flow operations. (See the graphic below.)

PQ Analysis

No.	Part No.	Quantity	Cumulative Total	%	Cumulative %
1	80-904212	20,190,000	20,190,000	16.2	16.2
2	90-801234	15,230,000	35,420,000	12.2	28.3
3	80-903123	10,200,000	45,620,000	8.2	36.5
4	80-902123	7,900,000	53,520,000	6.3	42.8
5	80-901123	7,400,000	60,920,000	5.9	48.7
6	89-801234	5,670,000	66,590,000	4.5	53.3
		66,590,000	282,260,000		

Once the Quick-Lite team identifies these products in a PQ analysis table, they create a process route table to determine whether a similar technology is used to manufacture all six types of spark plugs.

What is a process route table, and how do I use one?

A *process route table* shows the machines and equipment required for processing a component or completing an assembly process. Such a table helps you to arrange your equipment in production lines according to product type and to group related manufacturing tasks into work cells. You can also use a process route table to analyze process, function, or task-level activities.

The steps for creating a process route table are as follows:

1. Somewhere above the top of the table, write the following:
    a. The name or number of the department whose activity is being analyzed.
    b. The operation or product that is being analyzed.
    c. The name of the person completing the form.
    d. The date on which the form is completed.
2. Use the "No." column on the left for the sequential numbering of the products or operations being analyzed.
3. For each product or operation you are analyzing, enter the item name, machine number, or function.
4. For each product or operation, enter circled numbers in the various resource columns that correspond to the sequence in which the resources are used for that product or operation.
5. Connect the circled numbers with lines or arrows to indicate the sequence of operations.

Once you have completed the table, look for items or products that follow the same, or nearly the same, sequence of machine and/or resource usage. You might be able to group these machines and/or resources together in the same work cells to improve the efficiency of your operations. (See the sample process route table below.)

Process Route Table

No.	Part No.	Process Name							
		Cut	Machine	Machine	Machine	Thread	Thread	Weld	Weld
		Machine No.							
		C1	M1	M2	M3	T1	T2	W1	W2
1	80-904212	①	②			③		④	
2	90-801234	①		②			③		④
3	80-903123	①	②			③		④	
4	80-902123	①	②			③		④	
5	80-901123	①			②		③		④
6	89-801234	①			②		③		④

Before you begin rearranging your equipment and work cells to accommodate a one-piece-flow method, be sure to create a process capacity table to analyze your current machine and employee capacity. (See chapter 7, "Standard Operations," for details about creating a process capacity table.)

What are the final steps?

The next step is to create a *standard operations combination chart*. This chart enables you to study the work sequence for all your organization's work processes. In such a chart, each task is listed sequentially and then broken down into manual, automated, wait, and walk times. (See chapter 7 for details about creating a standard operations combination chart.)

Finally, you should create a *workflow diagram*, which shows your organization's current equipment layout and the movement of materials and workers during your work processes. It helps you identify areas of waste and plan improvements to your work cells that will enable you to implement one-piece-flow production. (See chapter 7 for details about creating a workflow diagram.)

Once your work team a) collects all the data necessary for selecting the products that are suitable for one-piece flow, b) verifies the operations needed and the available capacity, and c) understands the specific task in detail, you can implement the layout of your improved work cells and make one-piece flow a reality in your organization.

Chapter 9

The Kanban System

What is it?

The kanban system is a method of using cards as visual signals for triggering or controlling the flow of materials or parts during the production process. It synchronizes the work processes within your own organization as well as those that involve your outside suppliers.

What does it do?

In the kanban system, a card (called a kanban) controls the movement of materials and parts between production processes. A kanban moves with the same materials all the way down the production line. When a process needs more parts or materials, it sends the corresponding kanban to the supplier; the card acts as the work order. A kanban card contains the following data:

- What to produce
- How to produce it
- When to produce it
- How much to produce
- How to transport it
- Where to store it

Why use it?

In an ideal world, demand for products would be constant. Organizations could always operate at maximum efficiency, producing exactly what was needed—no more, no less. But for most companies, the amount of work that must be done varies by the day, week, or month.

An organization must have enough capacity so that there are enough people, machines, and materials available to produce what is needed at times of peak demand.

But when there is a smaller amount of work to be done, one of two things can happen: 1) underutilization of people, machines, or materials or 2) overproduction.

With the kanban system, workers are cross-trained to be knowledgeable about various machines and work processes so that they can work on different manufacturing tasks as needed. This prevents underutilization.

Kanban systems also prevent overproduction, which is the single largest source of waste in most manufacturing organizations. When you use the kanban system correctly, no overproduction will occur.

The kanban system also gives your organization the following positive results:

- All employees always know their production priorities.
- Employees' production directions are based on the current conditions in your workplace.
- Employees are empowered to perform work when and where it is needed. They do not need to wait to be assigned a work task.
- Unnecessary paperwork is eliminated.
- Skill levels among your employees are increased.

What skill and concepts do I need to know?

Before you can put the kanban system in place, you must first make your production process as efficient as possible. Two practices—production smoothing and load balancing—are helpful for doing this.

Production smoothing refers to synchronizing the production of your company's different products to match your customer demand. Once you successfully accomplish production smoothing, daily schedules for your production processes are arranged to ensure production of the required quantity of materials at the required time. Your employees and equipment are all organized toward that end as well.

To successfully do production smoothing, you first break down your required monthly production output into daily units using the following formula:

$$\text{required quantity per day} = \frac{\text{required quantity per month}}{\text{number of days of operation}}$$

Then you compare this daily volume with your operating hours to calculate the *takt time*, which is described in detail in chapter 7, "Standard Operations."

Calculating your takt time for production lets you determine how much to vary the pace of the work you must do.

The mathematical formula for determining your takt time is as follows:

$$\text{takt time} = \frac{\text{available daily production time}}{\text{required daily quantity of output}}$$

Then you look at your *capacity*, which is the ability of a machine and operator to complete the work required, and determine the number of employees required to complete your production processes.

> **Tip** Don't calculate your takt time based on the number of employees already working on your production line. That can result in too much or too little capacity. Instead, calculate your takt time based on the number of units required per day and then determine the number of employees needed to staff the line to produce at that rate.

Load is the volume of work that your organization needs to do. *Load balancing* is finding a balance between the load and your capacity. Timing and volume are critical to achieving load balancing.

> **Tip** Although kanban systems are a very effective way to fine-tune your production levels, they work best only after you have implemented value stream mapping (see chapter 3 for details) and one-piece flow (see chapter 8). This is because kanban systems minimize your stocking levels and use visual management (see chapter 4), error proofing (see chapter 5), and total productive maintenance (see chapter 10) to ensure that quality parts and materials are delivered when a kanban triggers their flow through the production process.

> **Tip** Perform maintenance and process-improvement activities during times of lower demand. This way, during peak demand times, every employee can be actively engaged on the production line.

> **Tip** The kanban system fine-tunes your production process. But it cannot make your organization able to quickly respond to sudden large changes in demand. You might not be able to rally sufficient resources to produce a very big order in time, or to find enough alternate activities to keep employees busy when there is a sudden large drop in orders.

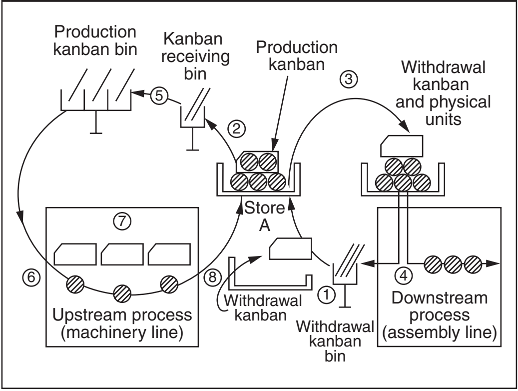
How does the kanban system work?

There are two basic types of kanban cards: *production* kanbans and *withdrawal* kanbans.

A production kanban describes how many of what item a particular operation needs to produce. Once employees have a production kanban in hand, their operation can begin producing the item.

A withdrawal kanban is used to pull items from a preceding operation or a *marketplace*, an area where materials are stocked in a supermarket system. The figure below shows the kanban system in use.

Withdrawal and Production Kanban Steps



1. An operator from the downstream process brings withdrawal kanbans to the upstream process's marketplace. Each pallet of materials has a kanban attached to it.

2. When the operator of the downstream process withdraws the requested items from the marketplace, the production kanban is detached from the pallets of materials and is placed in the kanban receiving bin.
3. For each production kanban that is detached from a pallet of materials, a withdrawal kanban is attached in its place. The two kanbans are then compared for consistency to prevent production errors.
4. When work begins at the downstream process, the withdrawal kanban on the pallet of requested materials is put into the withdrawal kanban bin.
5. At the upstream process, the production kanban is collected from the kanban receiving bin. It is then placed in the production kanban bin in the same order in which it was detached at the marketplace.
6. Items are produced in the same order that their production kanbans arrive in the production bin.
7. The actual item and its kanban must move together when processed.
8. When a work process completes an item, it and the production kanban are placed together in the marketplace so that an operator from the next downstream operation can withdraw them.

Tip A kanban card should be attached to the actual item it goes with so that it can always be accurately recognized.

What are the general guidelines for using the kanban system?

When using the kanban system, it's important to follow the six general guidelines listed below.

1. An upstream process never sends defective parts to a downstream process.
   a. Operators at a process that produces a defective product must immediately discover it.
   b. The problem(s) that created the defective product must be resolved immediately.
   c. Machines must stop automatically when a defect occurs.
   d. Employees must stop their work operation when a defect occurs.
   e. All defective products mixed with good products must be separated promptly.
   f. Suppliers who ship defective parts to your organization must send the same number of replacement parts in their next shipment. This ensures that the exact number of good parts required is available for production operations.
2. A downstream process withdraws only what it needs from an upstream process.
   a. No withdrawal of materials from a process is allowed without a kanban.
   b. Withdraw the same number of items as kanbans (unless a kanban indicates item quantities of more than one).
   c. A kanban must accompany each item.
3. An upstream process produces the exact quantity of products that will be withdrawn by the next process downstream.

   a. Inventory must be restricted to an absolute minimum. This is called *just-in-time inventory* (see the next page).
   b. Do not produce more items than the number of kanbans (unless a kanban indicates item quantities of more than one).
   c. Produce units in the order in which their production kanbans are received.

4. Synchronize your production processes by regularly maintaining your equipment and reassigning workers as needed.

5. Remember that the kanban system is a way of fine-tuning your production amounts.
   a. The kanban system cannot easily respond to major changes in production requirements. Your company also needs to have proactive sales and operations-planning procedures in place.
   b. The principles of load balancing must be followed.
   c. Employees receive work instructions for production and transportation of materials via kanbans only. No other production information is sent to employees.

6. Work to stabilize and improve your production processes. Variations and impractical work methods often produce defective materials. Make sure you keep all your work processes in control, and keep variation levels within the requirements of your customers.

What is a supermarket system, and how do I operate one?

Lean enterprises use a supermarket system to achieve just-in-time inventory. The concept of a supermarket system is similar to that of shopping at a supermarket. When you go to a supermarket, you do the following:

- Select the type and quantity of food you need, taking into account the number of people in your family, the space you have available to store goods, and the number of days the supply must last.
- Put the food items into a shopping cart and pay for them.

When you use a supermarket system for your organization's manufacturing operations, the following steps occur:

- The process that manufactures parts keeps them in a marketplace.
- When the marketplace is full, production stops.
- A downstream process requests parts from an upstream process only when it needs them.
- The responsibility for transporting materials from one process to another belongs to the downstream process that uses them.

A storage area for parts is called a marketplace because it is the place where downstream processes go to get the parts and materials they need.

For a supermarket system to work as efficiently as possible, the following must occur:

- No defective items are sent from a marketplace to downstream processes.
- Marketplaces are assigned the smallest space possible to fit the materials they must hold. A

marketplace is clearly defined by a line or divider, and no materials are stored beyond its boundaries.

- A minimum number of items is placed in each marketplace.
- Marketplaces are maintained with visual management techniques. (See chapter 4 for details.)

How do I use the kanban system for an automated assembly line?

LEADER

To implement the kanban system in an assembly line where no human operators oversee the production equipment, you must make some technical modifications. Automatic limit switches must be installed on your equipment to keep the machines from producing too many units. In addition, all your production processes should be interconnected so that they have the required quantity of standard stock on hand. A fully automatic kanban system is known as an *electric kanban*.

Can I use the kanban system for producing custom orders?

LEADER

A kanban system is an effective way of controlling the production of specialized parts or products that your organization makes. Using the kanban system for special parts or products ensures the following:

- Your starting and transporting procedures are conducted in the right sequence and on a constant basis.
- You can keep your stocking levels constant. This enables you to reduce your overall stocking levels.

Because companies do not ordinarily produce specialized parts on a regular basis, it's important for employees to share information about their production in a timely manner. Information delays can result in increases or decreases in the number of units you have on hand. Circulating your kanbans more frequently enables you to produce fewer batches of specialized parts more frequently.

How many kanbans should I use?

The number of kanbans you should use depends on the type of inventory-control system you have. There are two types: the *constant order-quantity* system and the *constant order-cycle* system.

With a constant order-quantity system, a downstream process orders a predetermined, fixed quantity of materials from an upstream process whenever inventory levels drop to a predetermined reorder point. This is the quantity level that automatically triggers a new order. Because the order quantity is fixed, the reorder date varies.

A constant order-cycle system, on the other hand, features a fixed reorder date and a varying order quantity. The quantity of materials ordered depends on the amount of materials used since the previous order was placed.

Both types of inventory-control system have pros and cons. Because the number of kanbans used in a constant order-quantity system always stays the same, this type of system makes it easy to error-proof your production operations for these constant, known quantities. Also, it is easy to apply visual management techniques to reflect constant stock levels and use of storage space. However, using a constant order-quantity system increases the complexity of coordinating the movement of materials throughout your plant.

A constant order-cycle system, on the other hand, reduces the complexity of coordinating the movement of materials throughout your plant. This makes this type of system ideal for production systems that use externally supplied parts, where coordinating fixed inbound freight dock times is critical. However, using a constant order-cycle system increases the complexity of managing the number of kanbans in the system because of variable production quantities within a fixed time period. Error-proofing and visual management techniques are also more difficult to use when production quantities vary significantly.

Tip The fewer kanbans you have, the better. Having too many kanbans means you have too much planned inventory. You should monitor and adjust your kanban levels so that you produce only the minimum amount of inventory required to keep your organization's downstream production assets running according to schedule. Too many kanbans, just like excess inventory, can hide problems.

Constant order-quantity system: reorder-point calculation

The reorder point is determined as follows.

- Reorder point:

  average usage during lead time + safety stock – orders placed but not yet received

- Total number of kanbans:

$$\frac{\text{economic lot size} + (\text{daily demand} \times \text{safety coefficient})}{\text{container capacity}}$$

or

$$\frac{\left[\dfrac{\text{monthly demand}}{\text{monthly number of setups}}\right] + (\text{daily demand} \times \text{safety coefficient})}{\text{container capacity}}$$

Constant order-cycle system: maximum inventory calculation

- Maximum inventory:

daily demand × (order cycle + lead time) + safety stock

Where the order cycle is the time interval between an order time and the next order time, and the lead time is simply the time interval between placing an order and receiving delivery.

- Order cycle:

$$\frac{\text{economic lot size for an expected demand}}{\text{daily average demand}}$$

- the economic lot size (Q) = $\sqrt{\dfrac{2AR}{ic}}$

where A = ordering cost per lot

R = monthly estimated demand quantity

i = carrying cost per dollar of an item

c = unit cost

- Order quantity:

(standard quantity – existing inventory) – (orders placed but not yet received)

- Total number of kanbans:

$$\frac{\text{daily demand} \times (\text{order cycle} + \text{lead time} + \text{safety period})}{\text{container capacity}}$$

where lead time = processing time + waiting time + conveyance time + kanban collecting time

More detailed explanations for the preceding equations are available from many industry sources, including *Toyota Production Systems: An Integrated Approach to Just-In-Time*, Third Edition, by Yashiro Monden (Engineering and Management Press, 1998).

Chapter 10

Total Productive Maintenance

What is it?

Total productive maintenance (TPM) is a series of methods that ensures every piece of equipment in a production process is always able to perform its required tasks so that production is never interrupted. It is a comprehensive, team-based, continuous activity that enhances normal equipment-maintenance activities and involves every worker.

What does it do?

TPM helps you focus on and accelerate the equipment improvements required for you to implement methods such as one-piece flow, quick changeover, and load leveling (see Glossary) as part of your company's lean initiative. TPM also helps to improve your first-time-through, or FTT (see Glossary), quality levels.

Why use it?

Using TPM results in many positive outcomes, including the following:

- Improved equipment performance. Equipment operators and maintenance workers prevent poor performance by conducting maintenance inspections and preventive maintenance activities. They also capture information about poor machine performance, enabling teams to diagnose declining performance and their causes. By preventing and eliminating these causes, these employees can improve performance efficiency.

- Increased equipment availability. TPM enables operators and maintenance workers alike to help prevent equipment failures by performing maintenance inspections and preventive maintenance activities. These employees also capture information regarding machine downtime, enabling your improvement team to diagnose failures and their causes. When you are able to prevent and eliminate the causes of failures, your asset availability improves.
- Increased equipment FTT quality levels. Process parameters that have a direct effect on product quality are called *key control characteristics*. For example, if a thermocouple in a furnace fails and an incorrect measurement is sent to the heating elements, this causes temperatures to fluctuate, which might significantly affect product quality. The goal of a TPM program is to identify these key control characteristics and the appropriate maintenance plan to ensure prevention of a failure of performance degradation.
- Reduced emergency downtime and less need for "firefighting" (i.e., work that must be done in response to an emergency).
- An increased return on investment, or ROI (see Glossary), in equipment.
- Increased employee skill levels and knowledge.
- Increased employee empowerment, job satisfaction, and safety.

How do I implement TPM?

Implementing TPM involves five steps.

1. Improve the effectiveness of your vital equipment.
2. Establish and implement autonomous maintenance.

3. Create a planned maintenance program.
4. Establish an equipment life-cycle management program.
5. Plan for and conduct continuous-improvement activities.

These five steps are described in detail below.

Step 1: Improve the effectiveness of your vital equipment.

The goal of your TPM program is to improve the reliability and performance of each piece of vital equipment in your production processes. *Overall equipment effectiveness* (*OEE*) is a metric that measures three aspects of equipment performance: availability, performance efficiency, and quality rate.

Your equipment must meet its design specifications for each of these three aspects to provide the greatest possible return on your company's investment.

It's important to target the most critical equipment first. Good choices include equipment that performs important processes or that performs marginally.

Once you have selected the equipment to target, you must then calculate the OEE for each machine, as well as the overall OEE of the line, processing unit, or entire plant. (See chapter 11, "Lean Metrics," for more information about calculating OEE.)

OEE is the primary measure of equipment performance. It measures how well your company's capital assets are used. The metric also shows the effect of equipment-related losses. The following seven types of equipment loss are useful ones to track:

1. Downtime due to machine breakdown.
2. Time required for setup and adjustments.

3. Time or cycles lost to inefficient setup.
4. Time or cycles lost to tooling.
5. Time or cycles lost to work stoppages.
6. Operating at less-than-ideal speeds.
7. Producing defective products that are rejected, require rework or repair, or are sold at a lower price.

Set a benchmark of 85% OEE for each piece of equipment. (The goal is usually not 100%; an OEE of 100% would leave no time for planned maintenance downtime or for running a piece of equipment at less than its design performance to avoid overproduction or to synchronize it with other pieces of equipment.) To motivate employees to make improvements, measure the lost revenue and increased costs that result when your equipment operates at a level that falls below this benchmark.

Use a Pareto Chart to display the data you collect; the highest bar on the chart indicates the greatest loss. For details and sample Pareto Charts, see pages 95–104 of *The Memory Jogger™ II*.

Your ultimate goal should be zero defects. Remember that if you can reduce defects to zero for an hour, then it's possible to reduce them to zero for an entire shift, an entire month, or even an entire year!

> ***Tip*** Make sure that your efforts to improve one OEE variable do not worsen other variables. For instance, don't increase a machine's performance efficiency if the machine will then fail more often or create more defects.

> ***Tip*** Correlate your OEE with your company's financial indicators. An improvement in OEE

can then be expressed in terms of additional profits or reduced costs, justifying additional capital expenditures.

Case example: Quick-Lite compares its OEE to the benchmark

Quick-Lite is a hypothetical company that manufactures spark plugs. The equipment the company uses to machine its spark-plug shells has the following OEE characteristics:

$$\text{Availability} = 90\%$$

$$\text{FTT quality} = 92\%$$

$$\text{Performance efficiency} = 95\%$$

$$\text{OEE} = 90\% \times 92\% \times 95\% = 79\%$$

This OEE of 79% does not quite meet the benchmark of 85%.

Step 2: Establish and implement autonomous maintenance.

In autonomous maintenance, equipment operators are trained to assume routine inspection and adjustment tasks normally performed by maintenance staff so that they can share the responsibility for the care of their equipment with the maintenance staff.

When equipment operators perform the routine tasks of maintenance, such as checking, adjusting, and lubricating equipment, maintenance workers are then free to work as analytical problem-solvers. They are able to focus on reliability-centered maintenance and product redesign, which results in permanent improvements.

Autonomous maintenance involves seven elements. They are outlined in the table below.

The Seven Elements of Autonomous Maintenance

Element	Purpose
1. Initial cleaning	• Reduces contamination. • Increases operator's familiarity with equipment and work area. • Uncovers hidden defects.
2. Preventive cleaning measures	• Identifies, isolates, and controls sources of contamination, including leaks, process-related excess, and materials from the external environment.
3. Development of cleaning and lubrication standards	• Combines inspections for cleanliness with lubrication checks so that they can both be performed as efficiently as possible.
4. General inspection	• Conduct torquing, adjustments, and minor calibrations. • Inspect hydraulic, pneumatic, and electrical subsystems.
5. Autonomous inspection	• Equipment operators assume responsibility for lubrication, cleaning, and general inspection of their equipment. • Operators must also be trained with regard to the technical aspects of the equipment.
6. Process discipline	• Improvement of methods and procedures to foster efficiency and repeatability. This has many benefits: 1. Reduced setup times. 2. Decreased manufacturing cycle times. 3. Standardized procedures for handling raw materials. 4. Visual control and inspection methods.
7. Independent autonomous maintenance	• Self-sustaining improvement.

Tip Before you can implement autonomous maintenance, your equipment operators need to receive basic technical, troubleshooting, and problem-solving training. In addition, maintenance personnel must receive advanced technical training, in addition to training in core trouble-shooting and problem-solving skills.

Maintenance staff or equipment manufacturers can train equipment operators about the basic care of their equipment. Some important tips to teach operators are listed below.

- Use only proper cleaning solutions and devices. Using improper chemicals can degrade product quality and/or corrode your equipment. Using incorrect cleaning tools can scratch or damage dies or fixtures.
- Eliminate unacceptable equipment vibration. Excessive vibration can be an indicator of bearing failure or loose mounts or bolts.
- Identify any worn or broken components. Equipment operators can often easily recognize worn tooling, broken gauges, nonfunctioning sensors, and loose drive belts. Replacing such failing components improves your company's OEE.
- Eliminate all sources of contamination. Foreign materials, such as dust and foodstuffs, can quickly wear out your equipment. Preventing contamination helps to prolong equipment life.

Before you begin your autonomous maintenance activities, ask the following questions:

1. Is our equipment's performance, availability, or product quality significantly affected by one or more of the following?
    - Workplace contamination

- Lack of lubrication
- Loose bolts or screws

2. Is our workplace made unsafe by one or both of the following?
    - Workplace contamination
    - Fluid leaks
3. Are there any routine, "low-skill" maintenance procedures that our equipment operators can perform that would also serve one of the following purposes?
    - Enhance the operator's sense of ownership over the quality of the area and the work
    - Minimize machine downtime
    - Extend machine life
4. Do our equipment operators and maintenance personnel have a good working relationship? Will the implementation of autonomous maintenance strengthen that relationship?

    Tip Those times during which there are no pressing equipment problems or production deadlines are good opportunities for maintenance personnel to thoroughly review equipment with the operators. This helps build proactive, positive relationships among coworkers. For more ideas about building cooperation and teamwork, consult *The Team Memory Jogger*™.

Step 3: Create a planned maintenance program.

The term *planned maintenance* refers to maintenance activities that are performed on a set schedule. The goal of a preventive maintenance program is the elimination of the need for *reactive maintenance*, which is maintenance activities that are performed after a piece of equipment breaks.

The four stages of maintenance are listed below.

The Four Stages of Maintenance	
Maintenance Stage	**Description**
Reactive	Responding to breakdowns.
Preventive	Periodic checking, adjusting, and replacing of parts to prevent failures.
Predictive	Forecasting potential problems by measuring process variables and the condition of the equipment.
Maintenance prevention	Improving equipment design to eliminate the need for maintenance.

Your equipment's design determines most of its maintenance needs. Many companies work with their equipment suppliers to develop machines that require fewer and less-complicated maintenance procedures.

Design engineers can reduce the amount of required maintenance by placing an emphasis on maintainability, flexibility, and robustness. When maintenance tasks are simplified, then less skill, time, and effort are required to maintain the equipment.

TPM programs are most successful in companies that use a computerized maintenance management system (CMMS). Below are the basic elements of a CMMS.

1. A work-identification system that:
    - Specifies the problem (e.g., a needed repair on a piece of equipment).
    - Identifies where the problem is.
    - Assigns a priority to the problem.
2. A work-authorization system that:
    - Sorts all work requests.
    - Eliminates duplicate requests.

- Decides which work can be safely postponed.
- Turns approved repairs into work orders that are planned, scheduled, and executed.

3. A work management system for the maintenance department that:
   - Identifies the equipment or area that needs work.
   - Establishes communication with the person who requested the work.
   - Diagnoses the problem.
   - Orders the needed parts and materials.
   - Schedules a time for the repair to take place.
4. A preventive-maintenance system that:
   - Schedules and performs periodic checks on equipment, lubrication, and the replacement of worn parts.
   - Triggers work orders.
   - Tracks compliance with the production schedule.
   - Correlates preventive maintenance activities with equipment reliability and availability.
5. A system that records the entire performance and repair history of all critical machines.
6. A cost-reporting system that records all costs related to equipment maintenance, including hidden costs caused by the following factors:
   - Poor maintenance.
   - Downtime.
   - Defective products.
   - Lost opportunities.
   - Lost and dissatisfied customers.

Step 4: Establish an equipment life-cycle management program.

An equipment life-cycle management program maximizes the return on your company's equipment investment.

Such a program has five phases. These are outlined in the table below.

Equipment Life-Cycle Management Program

Phase	Description
Specification	Identifies the functions and requirements of the equipment you intend to purchase.
Procurement	Matches your company's needs with a suitable external or internal equipment supplier.
Start-up or commissioning	The initial phase of the new equipment's operation. This phase lasts until the equipment reaches a stable state of operation.
Operation	Long-term supervision of the equipment. This includes production, maintenance, and rebuilding. The equipment generates value during its operation.
Disposal	Scrapping of all obsolete, deteriorating, or unneeded equipment.

Tip Don't treat the five equipment life-cycle phases as separate categories; instead, integrate your company's efforts by working together in cross-functional teams.

Tip To ensure that new equipment you purchase does the job for which it is intended, assemble a small team of design engineers, equipment suppliers, production engineers, shop-floor workers, and maintenance staff and have them take part in the design and selection of the equipment, as well as the start-up process.

Tip Practice good equipment management principles to improve maintainability. For example, replace bearings that require ongoing lubrication with sealed bearings. Review data collected during maintenance activities to determine unsatisfactory equipment component lives. Then specify better components for all new equipment that you purchase.

Step 5: Plan for and conduct continuous-improvement activities.

Equipment operators and maintenance, engineering, and supervisory personnel should all take an active role in planning your company's continuous-improvement initiatives. These initiatives can include autonomous maintenance, planned preventive maintenance, and asset management (i.e., all activities and tasks performed throughout the asset life cycle). This focuses your entire company on responding to existing equipment needs as well as identifying new ones.

Once your continuous-improvement plans are in place for both your existing and new equipment needs, individuals and teams should conduct directed activities and report on their progress. These plans should be integrated into your company-wide lean initiatives and Total Quality Management (TQM) activities.

What does a typical TPM plan look like?

The stages of a typical TPM plan follow the Plan-Do-Check-Act (PDCA) Cycle, a powerful approach for problem solving. (See *The Problem Solving Memory Jogger*™ for details.) A sample plan is outlined in the table on the next page.

Sample TPM Plan

Plan

1. Assess your equipment's current condition to establish a baseline for future comparisons and performance standards. It's important to track the following data:
   - The percentage of "firefighting" that you must do.
   - Equipment failure rates.
   - Your maintenance budget as a percentage of asset-replacement value.
   - Your OEE rating.
2. Prepare to implement your TPM program by completing the following steps:
   - Inform all involved employees about it. Tell them what the program is, and what they will be expected to do.
   - Change your company's organizational structure, if necessary, to support and promote your TPM program.
   - Communicate your support of TPM to all employees and your improvement team.
   - Establish measurable goals and objectives.
   - Create a master implementation plan.

Do

3. Improve the effectiveness of each piece of your vital equipment by making sure the following steps are accomplished:
   - Operators learn about and begin to share in the basic care of their equipment (i.e., autonomous maintenance).
   - The maintenance department establishes a maintenance plan for all equipment.
   - Operators and maintenance staff are trained on maintenance procedures.
   - The maintenance department develops a total life-cycle maintenance program for your equipment.

Check

4. Check the effectiveness of your maintenance program by regularly examining your equipment's failure rate, downtime, defect rate, and OEE data.

Act

5. Recommend changes to your maintenance procedures and continue the improvement process.
6. Recommend new or modified equipment and parts standards to extend equipment life, improve serviceability, and reduce maintenance requirements.

Case example: Quick-Lite starts a TPM program

The team at Quick-Lite decides to start a TPM program for the company's computer networks, which have experienced a significant number of software and hardware failures. They begin by categorizing the various problems they are having with their systems, as described below.

Category 1: Availability. Quick-Lite's network goes down at least once a week for fifteen minutes, which affects nearly 250 people in jobs ranging from accounting to shipping. In addition, complaints logged into the IT service center indicate that nearly 85% of all the company's PCs experience some form of hardware or software failure. Most of these failures are overcome through rebooting the system.

The IT group estimates that roughly 150 hours per week of productive work time are lost to computer downtime. This equates to $7,500 in lost productivity costs per week—nearly $375,500 per year.

Category 2: Performance Efficiency. When the team at Quick-Lite takes a closer look at why employees' PCs must be rebooted, they find that having duel sessions of their Enterprise Resource Planning (ERP) system and local programs consumes a large quantity of memory. This either slows down the system or locks it up entirely. Keyboard failures are another problem.

Category 3: Quality. The team at Quick-Lite finds that data entry is the largest source of errors in the company's computer system.

After working hard to improve the company's network uptime, the team launches an autonomous maintenance program with the company's PC users.

This program consists of the following steps:

1. **Initial cleaning.**

   PC cleaning and inspection workshops are conducted within each work area. PC users are given the latest antivirus software and a software cleanup tool. During the initial cleaning activities, a physical inventory of both hardware and software is taken.

2. **Preventive cleaning measures.**

   The Quick-Lite team finds that certain work areas, such as insulator manufacturing, have high concentrations of ceramic dust. After cleaning the keyboards, the team installs soft plastic keyboard covers. Team members also set up a preventive maintenance schedule to clean out contamination within the computers' CPUs regularly.

3. **Development of cleaning standards.**

   Based on the results of their initial- and preventive-cleaning measures, the team at Quick-Lite decides to purchase an additional module for the IT group's customer-service software. This module allows them not only to schedule maintenance activities but also to allocate labor, materials, and equipment costs to assets. This enables the IT group to ensure that routine maintenance, upgrades, equipment replacements, and system purges are conducted. Job plans and safety instructions are developed for routine computer maintenance and repair activities.

4. **General inspection.**

   The team posts computer inspection guidelines within each work area, e-mails them to each user, and loads a reminder onto each PC. These guidelines include a schedule of the maintenance tasks to be done by IT personnel and PC operators.

5. **Autonomous inspections.**

   With the new cleaning tools and software in hand, each PC operator at Quick-Lite can now perform routine maintenance tasks. The IT group programs the cleaning software to conduct routine purges and defragmentation during a designated time established by each employee. A special internal web site is created to answer employees' most frequently asked questions about computer problems.

6. **Process discipline.**

   The team at Quick-Lite develops metrics to enable each work area to monitor its computer performance. This metric becomes the basis for a recognition system for the team that does the best job of improving the company's computer OEE.

7. **Independent autonomous maintenance.**

   Each department appoints at least one "power user," an employee who receives additional training about PC diagnostics and maintenance. This power user runs a weekly feedback and problem-solving meeting about the computer problems the department encountered during the previous week.

8. **Quick-Lite's computer problems soon begin to disappear.**

   Weekly maintenance activities are performed as expected, and Quick-Lite's PC operators are now able to conduct more difficult diagnostics on their own. Each department's weekly problem-solving meeting becomes a monthly, and then a quarterly, event.

Chapter 11

Lean Metrics

What are they?

Lean metrics are measurements that help you monitor your organization's progress toward achieving the goals of your lean initiative. Metrics fall into three categories: financial, behavioral, and core-process.

What do they do?

Lean metrics help employees understand how well your company is performing. They also encourage performance improvement by focusing employees' attention and efforts on your organization's lean goals.

Why use them?

Lean metrics enable you to measure, evaluate, and respond to your organization's current performance in a balanced way—without sacrificing the quality of your products or services to meet quantity objectives or increasing your product inventory levels to raise machine efficiency. Properly designed lean metrics also enable you to consider the important people factors necessary for your organization's success.

What are the objectives of using lean metrics?

1. After you use lean metrics to verify that you are successfully meeting your company's lean goals, you can do the following:
   a. Use the data you have collected to determine existing problems. Then you can evaluate and

prioritize any issues that arise based on your findings.

   b. Identify improvement opportunities and develop action plans for them.
   c. Develop objectives for performance goals that you can measure (e.g., 100% first-time-through quality capability = zero defects made or passed on to downstream processes).
   d. Evaluate the progress you have made toward meeting your company's performance goals.

2. Lean metrics help you analyze your business more accurately in the following areas:
   a. Determining critical business issues, such as high inventory levels that drive up operational costs, poor quality levels that create customer dissatisfaction, and extended lead times that cause late deliveries and lost orders.
   b. Determining whether you are adhering to lean metrics. These differ from traditional metrics, which can actually work against you. For example, adhering to traditional metrics such as machine efficiency can spur overproduction, and improving your inventory turnover can worsen your on-time-delivery performance.
   c. Determining the best way to use your organization's resources. For example, you can ask questions such as "What is our most frequent problem?" and "What is our costliest problem?"

How can I be sure I am collecting the right type of data?

Before your team begins to collect data, ask the following questions:

1. What is our purpose for collecting this data?
2. Will the data tell us what we need to know?
3. Will we be able to act on the data we collect?

Your goal is to create an easy-to-use, high-impact measurement system.

An easy-to-use system must require minimal human involvement. The higher the level of human involvement required, the lower the accuracy of the data and the more time needed for data collection. Try to find ways to automate your data collection and charting.

A high-impact measurement system is one that results in information that is useful and easily interpreted.

> **Tip** Use a standard definition form for your metrics. The form should answer the following questions:
>
> - What type of metric is it (financial, behavioral, or core-process)?
> - Why was it selected?
> - Where will the data be obtained?
> - How will the data be collected?
> - What formula will be used for calculating the metric?
> - How often will it be calculated?
> - How often will the metric be used?

Revise your definition form as needed.

Tip Use basic graphs (e.g., line, bar, and pie graphs) and statistical process control (SPC) charts to display your data. These charts give you insight into data trends, reveal whether true process changes have occurred, and show if the process is capable of achieving your desired performance objectives. Other data-analysis techniques might be required to conduct effective problem solving. (See chapter 5, "Error Proofing," for details.)

How do I design a data-collection process?

LEADER

When you design your data-collection process, keep the following points in mind:

- Make sure that all employees who will collect the data are involved in the design of your data-collection process.
- Tell employees that the main driver for data collection is process improvement, not finger-pointing.
- Tell all involved employees how the data will be used.
- Design data-collection forms to be user-friendly.
- When developing a data-collection procedure, describe how much data is to be collected, when the data is to be collected, who will collect the data, and how the data is to be recorded.
- Automate data collection and charting whenever possible.
- Involve employees in the interpretation of the data.

Tip Avoid the following pitfalls:

- Measuring everything. Focus instead on the few critical measures that can verify performance levels and guide your improvement efforts.
- Misinterpreting data. Show employees why and how the data was captured. Also tell how the data will be used in your lean enterprise initiative.
- Collecting unused data. Data collection is time consuming. Ensure that all the data you collect will be put to good use.
- Communicating performance data inappropriately. Avoid creating harmful fault-finding, public humiliation, or overzealous competition.

Tip Remember to use the appropriate tools for your analysis. Less-experienced teams can use basic tools such as Pareto Charts, Histograms, Run Charts, Scatter Diagrams, and Control Charts. Refer to *The Memory Jogger™ II* for insight on the purpose and use of these tools. More-expert teams can use advanced tools such as regression analysis, design of experiments, and analysis of variance (ANOVA).

Tip Most metrics reveal ranges of values and averages of multiple measures. However, your customers rarely experience an "average." Each opportunity for a defect is an opportunity for failure in your customers' eyes.

Tip As you work toward improvement, you might find that solving the smallest problems takes up most of your time. You might spend 80% of your improvement efforts fixing 20% of the things that go wrong.

What are financial metrics, and how do I implement them?

You improve your organization's financial performance by lowering the total cost of operations and increasing revenue. If your company can become a lower-cost producer without sacrificing quality, service, or product performance, it can strengthen its performance and market position.

Examples of Financial Metrics

Costs

- Cash flow
- Direct and indirect labor costs
- Direct and indirect materials costs
- Facility and operational costs
- Production systems
- Information systems
- Inventory-carrying costs
- Total cost of ownership

Revenue

- Sales
- Gross margins
- Earnings before interest and taxes
- Return on assets
- Return on investment
- Warranty costs
- Product profitability

When making revenue or savings projections, it's important to understand the difference between hard- and soft-cost savings. *Hard-cost savings* actually produce cash savings or profit increases. They directly affect your company's profit-and-loss statement.

*Soft-cost saving*s are assets that are freed up so they can be used for another purpose. This contributes no positive change to a company's P&L statement.

It's also important to avoid *cost shifting*, which is the act of moving costs from one account to another without creating any real savings. Cost shifting often hides waste rather than removing it. Your ultimate goal is to reduce both your hard- and soft-cost savings for the benefit of the whole organization.

Case example: Quick-Lite implements a quick-changeover initiative

Quick-Lite is a hypothetical company that manufactures spark plugs. Its improvement team decides to implement a quick-changeover initiative for the company's shell-fabrication line. This enables Quick-Lite to reduce its batch sizes by a full 65% and its inventory investment by 35%. These are both hard-cost savings.

Before Quick-Lite implemented its cost-reduction efforts, employees were responsible for all aspects of inventory and stocking. Now Quick-Lite requires one of its suppliers to inventory and stock all raw materials at its own site. By doing this, Quick-Lite frees up nearly 50% of its storage space, for which it has no plans for other uses. This is a soft-cost savings.

By requiring one of its suppliers to inventory and stock raw materials at its own site, Quick-Lite has shifted the cost of stocking the raw material to its supplier. However, the supplier might now decide to pass this expense back to Quick-Lite in the form of higher prices, which Quick-Lite might have to pass along to its customers.

Tip Introduce financial metrics to employees as a way for them to understand the impact of their lean efforts on operations as well as on the company's bottom line.

Tip Encourage the use of financial metrics in your team-based improvement activities. Provide training when necessary.

What are behavioral metrics, and how do I implement them?

Behavioral metrics are measurements that help you monitor the actions and attitudes of your employees.

Employees' commitment, communication, and cooperation all have a significant impact on your organization's success. Financial and core-process metrics alone cannot show whether employees are working together in a cooperative spirit. Your company's long-term success is possible only when employees' behavior is aligned and everyone works for the benefit of the entire organization.

Behavioral Categories and Metrics

Category: Commitment

Performance Metrics
- Adherence to policies and procedures
- Participation levels in lean improvement activities
- Availability and dedication of human-resources department
- Efforts to train employees as needed

Category: Communication

Performance Metrics
- Customer/employee surveys regarding quantity and quality of company communications efforts
- Elimination of service or production errors caused by ineffective communications
- Error-reporting accuracy and timeliness
- Formal recognition of employees' communication efforts

Category: Cooperation

Performance Metrics
- Shared financial risks and rewards
- Effective efforts toward reporting and resolving problems
- Joint recognition activities
- Formal recognition of employees' cooperation efforts

Tip Customer and employee satisfaction surveys and core-process metrics measure behavioral performance only indirectly. More effective and direct ways to measure it include project feedback, meeting evaluations, employee appraisals, and peer evaluations.

Tip Conduct teamwork and facilitation training to improve cooperation and communication within your organization. See *The Team Memory Jogger*™ and *Facilitation at a Glance!*™ for details.

Tip Make sure your reward-and-recognition system is aligned with your company's lean goals. See *Performance Management: A Pocket Guide for Employee Development*™ for details.

What are core-process metrics, and how do I implement them?

There are many different types of core-process metrics, which allow you to measure the performance of your core processes (see Glossary) in different ways.

Be sure to measure all your core processes for both productivity and results. *Productivity*, the ratio of output to input, provides data about the efficiency of your core processes. Tracking the results and then comparing them to your desired outcomes provides you with information about their effectiveness. Some general core-process metrics are shown in the table below.

Core-Process Metrics
• New product launches • New product extensions • Product failures • Design-cycle time • Time to market • Product life-cycle profitability

Product life-cycle metrics include the identification of market potential, product design, new product launches, model extensions, product use, and product obsolescence.

Order-fulfillment-cycle metrics include activities related to sales, engineering, procurement, production planning and scheduling, the production process, inventory management, warehousing, shipping, and invoicing.

Some specific core-process metrics are shown in the table below. These metrics are explained in detail on the following pages.

Core-Process Metrics	
Results Metrics	**Productivity Metrics**
• Health and safety (HS) • First-time-through (FTT) quality • Rolled-throughput yield (RTY) • On-time delivery (OTD) • Dock-to-dock (DTD) • Order-fulfillment lead time (OFLT)	• Inventory turnover (ITO) rate • Build to schedule (BTS) • Overall equipment effectiveness (OEE) • Value-added to non-value-added (VA/NVA) ratio

What are health and safety metrics?

Health and safety (HS) metrics measure the impact of your production processes on employees' health and safety.

Why use them?

A wholesome and safe workplace improves the availability and performance of your organization's human resources. Operations costs improve when insurance rates are lowered, the cost of replacing workers is reduced, and production assets are more available. In addition, improved morale and a sense of well-being increase employee productivity and participation in your company's improvement initiatives.

HS conditions can be measured in several ways. Metrics to consider when evaluating HS include days lost due to accidents, absenteeism, employee turnover, and experience modification ratio (EMR), a method used by insurance companies to set rates. (A detailed explanation of EMR is beyond the scope of this book.)

What is first time through (FTT)?

First time through (FTT) is a metric that measures the percentage of units that go through your production process without being scrapped, rerun, retested, returned by the downstream operation, or diverted into an off-line repair area. This metric is also applicable to processes related to services your company provides. For example, you can use it to measure the number of sales orders processed without error the first time they go through your work processes.

Why use it?

- Increased process/output quality reduces the need for excess production inventory, improving your dock-to-dock (DTD) time. (See page 138 for a definition of DTD.)
- It improves your ability to maintain proper sequence throughout the process, improving the build-to-schedule (BTS) metric. (See page 143 for a definition of BTS.)
- Increasing quality before the constraint operation (see Glossary) occurs ensures that that operation receives no defective parts. This enables you to increase your quality rate and

reduce defects at the constraint operation. This in turn improves the overall-equipment-effectiveness (OEE) metric. (See page 147 for a definition of OEE.)

- Your organization's total cost is improved due to lower warranty, scrap, and repair costs.

FTT is calculated using the following formula. (Remember that "units" can be finished products, components, or sales orders; FTT's use is not limited to a production environment.)

$$\text{FTT} = \frac{\text{units entering process} - (\text{scrap} + \text{reruns} + \text{retests} + \text{repaired off-line} + \text{returns})}{\text{units entering process}}$$

Case example: Quick-Lite calculates its FTT

At Quick-Lite's spark-plug-shell machining center, 250,500 shells are produced during an eight-hour shift. Of these, 4,450 are scrapped; none are rerun, retested, or repaired; and 4,318 are returned by the downstream operation. This equals an FTT of 96.5%, as shown below.

$$\text{FTT} = \frac{250{,}500 - (4{,}450 + 0 + 4{,}318)}{250{,}500} = 0.965, \text{ or } 96.5\%$$

Quick-Lite can easily calculate the total FTT capabilities of its four operations involved in spark-plug-shell fabrication by multiplying the FTT results for each operation. These results are as follows: cut bar stock, 95%; machine shell, 96.5%; thread shell, 97%; and weld side wire, 98%.

With this data, Quick-Lite calculated its overall FTT as follows:

$$\text{FTT} = 95\% \times 96.5\% \times 97\% \times 98\% = 87\%$$

What is rolled throughput yield (RTY)?

Rolled throughput yield (RTY) is a metric that measures the probability that a process will be completed without a defect occurring. Six Sigma programs use this metric either instead of or in parallel with FTT.

RTY is based on the number of defects per opportunity (DPO). An *opportunity* is anything you measure, test, or inspect. It can be a part, product, or service characteristic that is critical to customer-quality expectations or requirements.

How does RTY differ from FTT?

FTT measures how well you create units of product; RTY measures how well you create quality. While FTT measures at the unit level and finds the percentage of defective parts, RTY measures at the defect level and finds how many defects a particular part has.

The RTY metric is sensitive to product complexity, as well as the number of opportunities for defects present in a production process or aspect of a service. RTY can help you focus an investigation when you narrow down a problem within a complex or multi-step process.

To calculate RTY, you must first calculate defects per unit (DPU) and defects per opportunity (DPO). The result is then used to calculate RTY.

$$\text{DPU} = \frac{\text{number of defects per unit}}{\text{total number of units}}$$

Defects per opportunity (DPO) is the probability of a defect occurring in any one product, service characteristic, or process step. It is calculated as follows:

$$\text{DPO} = \frac{\text{DPU}}{\text{opportunities per unit}}$$

Finally, RTY is calculated as follows:

$$RTY = 1 - DPO$$

Case example: Quick-Lite calculates its RTY

Quick-Lite has four operations involved in its spark-plug-shell fabrication process. Each operation has five opportunities and a DPO of 0.001. The RTY is calculated as follows:

$$1 - 0.001 = 0.999$$

$$RTY = (.999^5)^4 = (.995)^4 = 0.98$$

What is on-time delivery (OTD)?

LEADER

On-time delivery (OTD) is a metric that measures the percentage of units you produce that meet your customer's deadline. For this metric, a unit is defined as a line item on a sales order or delivery ticket.

Why use it?

- OTD provides a holistic measurement of whether you have met your customer's expectations for having the right product, at the right place, at the right time.
- You can use OTD to track deliveries at both the line-item and order levels. OTD alerts you to internal process issues at the line-item level and shows their effect on your customers at the order level.
- OTD ensures that you are meeting optimum customer-service levels. When you balance OTD with the other internally focused core-process metrics—build-to-schedule (BTS), inventory turnover (ITO) rate, and dock-to-dock (DTD)—you can meet your customer-service goals without making an excessive inventory investment.

OTD is calculated on an order-by-order basis at the line-item level using the following formula:

$$\text{OTD} = \frac{\text{line items received on time by the customer}}{\text{total line items received}}$$

Tip Sometimes OTD is measured at the order level rather than at the line-item level. When this is the case, the entire order is considered to be late if only one line item is late. Be sure to verify the level at which your customer wants OTD measured.

Case example: Quick-Lite calculates its OTD

Quick-Lite ships an order with six line items on it. One of these items is delivered late. If Quick-Lite tracks the OTD at the order level, then the total order is late, or 0% on time.

Last month, Quick-Lite shipped a total of 1,250 line items, of which 1,115 were delivered on time. Therefore, the monthly on-time delivery performance is 89.2%, as shown below.

$$\text{OTD} = \frac{1{,}115}{1{,}250} = .892\text{, or } 89.2\%$$

Tip If delivery occurs on the same day as the ship day, then you can use line items shipped on time to measure your OTD.

Tip In the case of delivery windows (i.e., specified time frames for deliveries), early deliveries might not be considered to be on time.

Tip Only the customer can choose to change the required delivery time.

Tip Track customer request dates as well as internal ship/promise dates whenever these two dates are not the same.

What is dock-to-dock (DTD)?

Dock-to-dock (DTD) is a metric that measures how long it takes raw materials or sub-components coming into your plant to be turned into finished products.

Why use it?

- Improving your DTD time improves your company's ability to make on-time deliveries.
- Improving your DTD time lowers your materials-handling, obsolescence, and inventory-carrying costs, which in turn leads to a lower total cost.
- Having decreased inventory levels leads to less storage and handling of materials. Thus, fewer opportunities to damage parts arise, and your FTT is improved.

DTD is calculated using the following formula:

$$\text{DTD} = \frac{\text{total number of control parts}}{\text{end-of-line rate}}$$

A *control part* is a significant component of the final product that travels through all the major manufacturing processes for that product.

The *end-of-line rate* is the average number of jobs per hour for a particular product. It is calculated using the following formula:

$$\text{end-of-line rate} = \frac{\text{manufactured units/week}}{\text{production hours/week}}$$

Case example: Quick-Lite calculates its DTD

Quick-Lite designated its R56T spark-plug shell as the control part. This shell goes through five distinct manufacturing processes before it is ready for shipment to the customer. Quick-Lite calculated its weekly DTD as follows:

$$\text{end-of-line rate} = \frac{43{,}440 \text{ units}}{48 \text{ hours}} = 905 \text{ units per hour}$$

Quick-Lite's current inventory of R56T spark-plug shells is as follows:

Current Inventory

Inventory Locations	Units in Area
Raw Materials	53,000
Cut	2,345
Machine	1,205
Thread	1,195
Weld	1,098
Assembly	14,480
Finished Goods	73,005
Total	146,328

$$\text{DTD} = \frac{\text{total units}}{\text{end-of-line rate}}$$

$$\text{DTD} = \frac{146{,}328 \text{ units}}{905 \text{ units/hour}} = 161.7 \text{ hours}$$

Quick-Lite also calculated its total DTD because it manufactures the control part during only six eight-hour shifts per week. The number of hours it would take to process all the units on hand in six eight-hour shifts per week is calculated as follows:

$$\text{Total DTD} = \text{DTD} \times \frac{\text{total hours/week}}{\text{production hours/week}}$$

$$\text{Total DTD} = 161.7 \text{ hours} \times \frac{168 \text{ hours}}{48 \text{ hours}} = 565.9 \text{ hours}$$

These calculations show that Quick-Lite, with nearly seventy-one days' worth of production in inventory, is like many other companies that make the mistake of purchasing large quantities of raw materials, running large batches, and overproducing.

> ***Tip*** Organizations often mistakenly compare their DTD measurement with their OTD. However, OTD does not measure invoice time; it stops at the point of shipment. By improving your DTD, you will automatically improve your OTD.

What is order-fulfillment lead time (OFLT)?

Order-fulfillment lead time (OFLT) is the average time that elapses between your company's receipt of an order from a customer and when you send an invoice to your customer for the finished product or service. It extends the DTD metric to include all your sales order-entry, sales-engineering, production-planning, and procurement lead times before production, as well as your invoicing lead times after production.

Why use it?

The time from receipt of a sales order to the time of receipt of payment is a measure of your company's operating cash flow. This is the money that your company uses to invest in its human resources, materials, equipment, and facilities. How your company manages its cash flow affects the company's ability to acquire investors and borrow the money it needs to expand its business.

Case example: Quick-Lite calculates its OFLT

Quick-Lite developed its OFLT calculation based on the average time the company took to perform the following separate operations. (The team decided to exclude receipt of payment from their calculations.)

- Sales order (SO): The time from when an order is received until the time it is entered into the production-scheduling system.
- Production scheduling (PS): The time from when an order enters the production-scheduling system until the time actual production begins.
- Manufacturing (M): The time from when a manufacturing order is started until the order is released to the shipping department.
- Shipping (S): The time from when an order is received in the shipping department until it leaves the dock.
- Invoice (I): The time from when accounting is notified of a shipment going out until it sends the invoice to the customer.

Thus, OFLT = SO + PS + M + S + I.

For Quick-Lite, OFLT = 1 + 2 + 5 + 2 + 2 = 12 days.

Tip Some companies break down their OFLT into separate financial measures, such as sales days outstanding (i.e., the average number of equivalent sales days currently out in receivables). This breakdown is often called quote-to-cash cycle time.

Tip To focus your team's efforts, consider breaking down the OFLT into discrete measures within each functional area (e.g., sales, engineering, scheduling, procurement, and accounting), as shown in the Quick-Lite example above. Have each functional area develop value stream maps and then focus its improvement efforts on waste elimination and lead-time reduction.

What is inventory turnover (ITO) rate?

Inventory turnover (ITO) rate is a metric that measures how fast your company sells the products you make—that is, how efficient your marketing efforts are.

Why use it?

- Inventory costs are a significant portion of your company's total logistics-related costs.
- Your inventory levels affect your customer-service levels, especially if a customer's order lead time is less than your manufacturing lead time.
- Your company's decisions regarding service levels and inventory levels have a significant effect on how much of the company's money is tied up in inventory investment. This is commonly referred to as "inventory carrying cost."
- High ITO rates reduce your risk of inventory loss and keep your return-on-assets rates competitively high.
- A low ITO rate can indicate excess inventory or poor sales—both bad signs. A high ITO rate, on the other hand, can indicate high efficiency.

Most companies struggle with low, single-digit ITO rates. The goal of most lean organizations is to achieve at least a double-digit ITO rate. A few exceptional companies are able to achieve triple-digit ITO rates across all their product lines.

ITO is calculated using the following formula:

$$\text{ITO} = \frac{\text{cost of goods sold (COGS)}}{\text{year-end inventory (taken from your company's balance sheet)}}$$

Case example: Quick-Lite calculates its ITO

The people at Quick-Lite thought they were only in the spark-plug business. What they didn't realize, until they did the calculations below, was that they were also in the spark-plug *inventory* business.

$$\text{ITO} = \frac{\$275{,}000{,}000}{\$63{,}953{,}500} = 4.3 \text{ turns}$$

Tip Some companies calculate their ITO rates based on measurements other than COGS. Some use yearly sales. Raw-materials producers often use the average purchase price for raw materials. Other companies estimate the average value of the work-in-progress (WIP) components at each production step.

What is build to schedule (BTS)?

LEADER

Build to schedule (BTS) is a metric that measures the percentage of units scheduled for production on a given day that are actually produced on the correct day, in the correct mix, and in the correct sequence.

Why use it?

- BTS measures your company's ability to produce what your customers want, when they want it, and in the scheduled production order.
- BTS alerts you to potential overproduction situations.
- BTS enables you to lower your inventory levels and improve your DTD time.
- The lower materials-handling and inventory-carrying costs that should result when you use BTS lead to improved total cost results for your company.

BTS is calculated using the following formula:

$$\text{BTS} = \text{volume performance} \times \text{mix performance} \times \text{sequence performance}$$

The calculation for determining volume performance is as follows:

$$\text{volume performance} = \frac{\text{actual number of units produced}}{\text{scheduled number of units}}$$

where "actual number of units produced" is the number of units of a given product to come off the end of the line on a given day, and "scheduled number of units" is the number of units of a given product scheduled to be produced. The result of the calculation is a percentage.

The calculation for determining mix performance is as follows:

$$\text{mix performance} = \frac{\text{actual number of units built to mix}}{\text{actual units produced or units scheduled to be produced}}$$

where "actual number of units built to mix" is the number of units built that are included in the daily production schedule (i.e., no overbuilds are counted). You can use either the number of actual units produced or the number of units scheduled to be produced, whichever is lower.

The calculation for determining sequence performance is as follows:

$$\text{sequence performance} = \frac{\text{actual number of units built to schedule}}{\text{actual units built to mix}}$$

where "actual number of units built to schedule" equals the number of units built on a given day in the scheduled order.

Case example: Quick-Lite calculates its BTS performance

Quick-Lite was painfully aware of its schedule mix-ups, overproduction, and inability to consistently match its production schedules to the ship dates that had been promised to its customers. The company decided to use BTS as a measure to ensure compliance to the scheduling and production requirements. What follows is a description of how Quick-Lite calculated its BTS performance.

The company had scheduled three types of spark plugs for one day's production. The table below shows the three spark-plug types and their build sequences:

Spark-Plug Types and Build Sequences

Spark-Plug Type	Build Sequence	Assemblies Scheduled
R56T	1	7,240
45TS	2	12,500
37CTS	3	3,450
Total		23,190
Spark-Plug Type	**Actual Sequence**	**Assemblies Built**
R56T	1	6,250
37CTS	2	3,375
45TS	3	13,900
Total		23,525

$$\text{Volume} = \frac{23{,}525}{23{,}190} = 1.01, \text{ or } 100\%^{*}$$

*No credit is given for overproduction.

Using the formula shown on the previous page, Quick-Lite calculated its mix performance as follows:

Mix Performance

Spark-Plug Type	Assemblies Built to Mix
R56T	6,250
37CTS	3,375
45TS	12,500
Total	22,125

$$\text{Mix} = \frac{22{,}125}{23{,}190} = 0.954\text{, or } 95.4\%$$

Quick-Lite's sequence performance is as follows:

Sequence Performance

Spark-Plug Type	Scheduled Sequence	Actual Sequence	Assemblies Built to Sequence
R56T	1	1	6,250
37CTS	3	2	3,375
45TS	2	3	0 (37CTS built before 45TS)
Total			9,625

$$\text{Sequence} = \frac{9{,}625}{22{,}125} = 0.435\text{, or } 43.5\%$$

This day's performance, then, was as follows:

$$\text{BTS} = 100\% \times 95.4\% \times 43.5\% = 41.5\%$$

Thus, Quick-Lite succeeded in making its volume goal; however, it did not produce the correct quantities in the correct sequence. Instead, it overproduced—and, because of schedule mix-ups, it missed customer-delivery windows.

What is overall equipment effectiveness (OEE)?

LEADER

Overall equipment effectiveness (OEE) is a metric that measures the availability, performance efficiency, and quality rate of your equipment. It is especially important to calculate OEE for your constraint operation.

Why use it?

- A higher throughput rate reduces the time your equipment spends in process, thereby decreasing your total DTD time.
- More stable processes improve your production predictability, thereby improving your BTS.
- Higher throughput and lower rework and scrap costs lead to improved total costs.

OEE is calculated using the following formula:

$$\text{OEE} = \text{equipment availability} \times \text{performance efficiency} \times \text{quality}$$

The calculation for determining equipment availability is as follows:

$$\text{Equipment availability} = \frac{\text{operating time}}{\text{net available time}}$$

"Operating time" is the net available time minus all other downtime (i.e., breakdowns, setup time, and maintenance). "Net available time" is the total scheduled time minus contractually required downtime (i.e., paid lunches and breaks).

Case example: Quick-Lite calculates its OEE performance

Quick-Lite calculated its spark-plug-shell machining center's equipment availability as follows:

Equipment Availability	
Machine #5127	**Calendar Week: 35**
A. Total scheduled time	6,000 minutes
B. Required downtime	500 minutes
C. Net available time (A–B)	5,500 minutes
D. Other downtime	850 minutes
E. Operating time (C–D)	4,650 minutes

$$\text{Equipment availability} = \frac{4{,}650 \text{ minutes}}{5{,}500 \text{ minutes}} = 0.845, \text{ or } 84.5\%$$

The calculation for determining performance efficiency is as follows:

$$\text{performance efficiency} = \frac{\text{total parts run} \times \text{ideal cycle time}}{\text{operating time}}$$

where "total parts run" equals the total number of parts produced (regardless of quality), and "ideal cycle time" equals the greatest of the following: the normal expected cycle time (in seconds per part) for the equipment; the best cycle time ever achieved and sustained for that piece of equipment; and an estimate based on experience with similar equipment.

Quick-Lite calculated the performance efficiency of its spark-plug-shell machining center as follows:

$$\text{performance efficiency} = \frac{\begin{array}{c}0.0167 \text{ minutes}\\ \times 250{,}500\end{array}}{4{,}650} = 0.898, \text{ or } 89.8\%$$

The calculation for determining quality is as follows:

$$\text{quality} = \frac{\text{total parts run} - \text{total defects}}{\text{total parts run}}$$

where "total defects" equals the number of rejected, reworked, or scrapped parts.

This is identical to the FTT calculation shown on page 134. Quick-Lite calculated the quality of its spark-plug-shell machining center as follows:

$$\text{quality} = \frac{250{,}500 - (4{,}450 + 0 + 4{,}318)}{250{,}500} = 0.965, \text{ or } 96.5\%$$

Quick-Lite then calculated the OEE performance for its spark-plug-shell machining center as follows:

$$\text{OEE} = 84.5\% \times 89.8\% \times 96.5\% = 73.2\%$$

> ***Tip*** Do not compare OEE results for non-identical machines or processes. An OEE comparison should be done only at time intervals for the same machine or the same process; otherwise, it is meaningless.

What is the VA/NVA ratio?

The value-added to non-value-added (VA/NVA) ratio is a metric that compares the amount of time in your work process spent on value-added activities to the amount of time spent on non-value-added activities.

Why use it?

- It makes non-value-added activities evident.
- It focuses your lean improvement efforts on the elimination of waste and the reduction of lead time.
- It provides a common metric for your management, sales, engineering, production, and procurement departments to communicate their priorities to each other and conduct cross-functional improvement activities.

VA/NVA ratio is calculated using the following formula:

$$\text{VA/NVA} = \frac{\text{total value-added activities time}}{\text{total OFLT}}$$

Case example: Quick-Lite calculates its VA/NVA ratio

To determine their total value-added activities time, the team at Quick-Lite developed a value stream map of their order-fulfillment process. They observed or calculated times for each activity. From this map they were able to identify the value-added and non-value-added activities.

From these results, the Quick-Lite team considered only their order-entry and manufacturing activities as value-added. Because all other activities were necessary but did not add value to the product, they were considered to be non-value-added activities.

Quick-Lite's weekly production hours included three daily shifts for five days, for a total of twenty hours per day (100 hours per week). The team at Quick-Lite calculated their VA/NVA performance as follows. (See the section on OFLT for details on the meaning of the letters used in the equation below.)

$$\text{VA} = \text{SO} + \text{PS} + \text{M} + \text{S} + \text{I}$$

$$\text{VA} = 10 + 0 + 235 + 0 + 0 = 245 \text{ minutes}$$

Recall that the Quick-Lite team calculated their OFLT as follows:

$$\text{OFLT} = \text{SO} + \text{PS} + \text{M} + \text{S} + \text{I}$$

$$\text{OFLT} = 1 + 2 + 5 + 2 + 2 = 12 \text{ days}$$

$$\text{VA/NVA} =$$

$$\frac{245 \text{ minutes}/60 \text{ minutes per hour}}{8 \text{ hours} + 16 \text{ hours} + 100 \text{ hours} + 16 \text{ hours} + 16 \text{ hours}} = 0.026 \text{ , or } 2.6\%$$

The result of 2.6% was an eye-opener for the team at Quick-Lite. They conducted a benchmarking study and found that most companies that perform this calculation do so for their manufacturing processes only. Their manufacturing-only VA/NVA percentages ranged from about 15% to 35%. However, adding their sales, production-planning, shipping, and invoicing times significantly reduced their VA/NVA ratio.

> **Tip** To focus your efforts, consider breaking the VA/NVA ratio into discrete measures within each functional area of your company (e.g., sales, engineering, scheduling, procurement, and accounting). Have each functional area develop value stream maps (see chapter 3 for details) and focus its improvement efforts on waste elimination and lead-time reduction.

How do I decide what performance metrics to use?

LEADER

Your goal is to select the metrics that accurately portray your company's performance. The best approach is to balance the metrics you use among the three categories (financial, behavioral, and core-process) and to use a mix of in-process and end-of-process metrics.

You should also consider the total number of metrics you use. Using too many can confuse employees and slow your performance-improvement efforts. Using too few might not provide you with enough detail to properly focus your improvement efforts.

When deciding which metrics to use, consider the following points:

- What are you measuring?
- What will be the frequency of measurement?
- How long will data be collected?
- Who will measure it?
- How will it be measured?
- How will it be charted?
- What action will be taken after the data is interpreted?
- Who will be responsible for follow-up action?

An Example of a Balanced Measurement Selection

<table>
<tr><th colspan="5">Category: Financial</th></tr>
<tr><th>Measurement</th><th>Freq.</th><th>Who Measures?</th><th>How Measured?</th><th>How Charted?</th></tr>
<tr><td>Cost reductions</td><td>Monthly</td><td>Improvement teams</td><td>Hard- and soft-cost transactional cost analysis</td><td>Bar chart indicating monthly and cumulative totals by location</td></tr>
<tr><td>Cost increases</td><td>Monthly</td><td>Improvement teams</td><td>Hard- and soft-cost transactional cost analysis</td><td>Bar chart indicating monthly and cumulative totals by location</td></tr>
<tr><th colspan="5">Category: Behavioral</th></tr>
<tr><td>Customer satisfaction</td><td>Yearly</td><td>Quality department</td><td>Customer survey—questions weighted by satisfaction and importance</td><td>Bar chart</td></tr>
<tr><td>Employee satisfaction</td><td>Yearly</td><td>Steering team</td><td>Employee survey—questions weighted by satisfaction and importance</td><td>Bar chart</td></tr>
<tr><td>Lean improvement initiative completions</td><td>Monthly</td><td>Improvement teams</td><td>Number of lean improvement initiatives completed with desired results</td><td>Bar chart indicating monthly and cumulative totals by location</td></tr>
</table>

Category: Core-Process				
Measurement	**Freq.**	**Who Measures?**	**How Measured?**	**How Charted?**
On-time delivery	Monthly	Sales and manufacturing	OTD % at line-item level, by ship-to locations	Pareto Chart
BTS	Monthly	Production planning	Volume × mix × sequence	Chart of individuals and moving range
OEE	Monthly	Manufacturing	Availability × performance efficiency × FTT quality for constraining operation and lowest-availability assets	Chart of individuals and moving range
ITO rate	Monthly	Finance	Inventory turns (cost of goods sold ÷ average inventory value)	Chart of individuals and moving range
OFLT	Monthly	Aggregated by functions submitted to lean enterprise	Average OFLT by product family	Chart of individuals and moving range

Tip As you complete your measurement selection, set specific performance objectives to drive your evaluation and improvement efforts.

What is a lean enterprise scorecard?

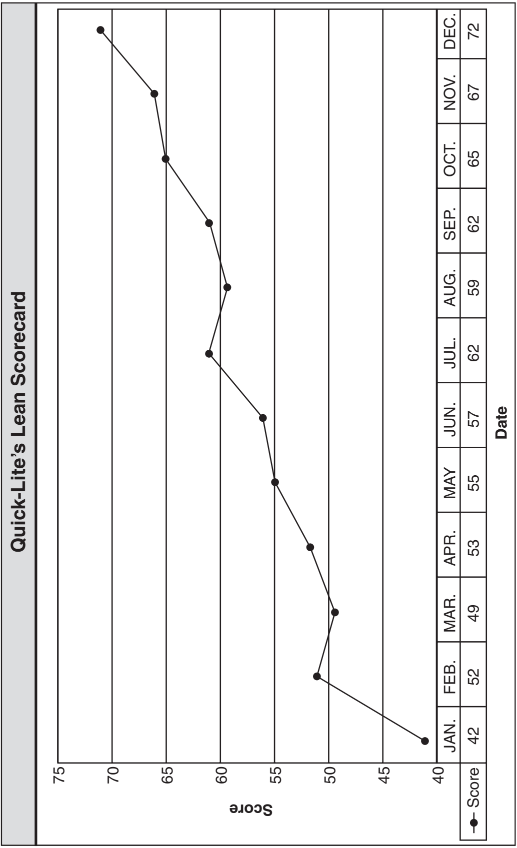
A lean enterprise scorecard is a technique for comparing your actual results to your performance objectives.

Below is Quick-Lite's scorecard. It shows how the company used scoring to gauge its overall progress toward its goals. (See Scoring Guide on page 156.)

Monthly Performance by Site: May

		Site A		Site B		Site C	
Category	**Goal**	**Actual**	**Score**	**Actual**	**Score**	**Actual**	**Score**
1. Monthly cost reductions (% of operating budget)	0.5%	0.45%	6	0.6%	10	0.4%	4
2. Percentage of products having undergone a lean transformation	12%	15%	10	10%	4	9%	2
3. Improvement suggestions	25	21	4	17	0	12	0
4. FTT quality	100%	92%	6	81%	4	78%	2
5. OTD (based on line items shipped)	98%	97% (of 128)	8	94% (of 124)	8	99% (of 198)	10
6. DTD	10 days	12	6	14	2	15	0
7. BTS	100%	75%	2	90%	6	85%	4
8. OEE for constraining operation	Per target: no less than 85%	Target = 95% 89%	8	Target = 94% 79%	4	Target = 93% 88%	6
9. ITO rate	5	4.6	6	4	4	3.9	2
10. OFLT	5 days	5 days	10	7 days	6	6 days	8
Totals (out of a possible 100 points)			66		48		38

Quick-Lite's Lean Scorecard for One Calendar Year



Scoring Guide			
Percentage of Goal		**Days to Complete Goal**	
100%:	10 points	≤ 0 days:	10 points
95–98%:	8 points	+1 day:	8 points
90–94%:	6 points	+2 days:	6 points
80–89%:	4 points	+3 days:	4 points
70–79%:	2 points	+4 days:	2 points
<69%:	0 points	+5 days:	0 points

Activity-Based Costing (ABC) An accounting technique that enables an organization to determine the actual cost of a product or service by tracing the cost back to the specific activities that produce or provide it. Compare to *Traditional Cost Accounting (TCA)*.

asymmetry When opposite sides of a part, tool, material, or fixture are different in size, shape, or relative position. Asymmetrical differences can be hard to spot, resulting in errors. Compare to *symmetry*.

autonomous maintenance A program in which equipment operators share responsibility with maintenance staff for the care of the equipment they use.

batch delay The amount of time a service operation or product unit waits while other operations or units in the lot, or batch, are completed or processed.

batch processing The movement of products through the manufacturing process in large numbers of identical units at once. Entire batches, or lots, are sent to each operation in the production process at the same time. Also known as *large-lot processing*. Compare to *one-piece flow*.

BTS (build to schedule) A metric that measures the percentage of units scheduled for production on a given day that are actually produced on the correct day, in the correct mix, and in the correct sequence.

capacity The ability of a machine and its operator to complete the work required.

constant order-cycle system An inventory-control system that features a fixed reorder date and a varying order quantity.

constant order-quantity system An inventory-control system that features a fixed order quantity and a varying reorder date.

constraining operation The manufacturing step that determines the upper limit on the number of finished parts that can be produced within a value stream. Also known as a *bottleneck operation*.

constraint operation An operation that is long in duration or is critical to completing a manufacturing process.

contact method An error-proofing method that involves inspecting the size, shape, or color of an object to determine if any deviations exist.

core processes The essential activities an organization must perform to produce products, complete order-fulfillment functions, maintain its assets, and complete all supporting business functions.

cost shifting Moving costs from one account to another without creating any real savings. Cost shifting often hides waste rather than removing it.

customer value An aspect of a product or service for which a customer is willing to pay.

cycle time The time it takes to successfully complete the tasks required for a work process.

defect A part, product, or service that does not conform to specifications or a customer's expectations. Defects are caused by errors.

demand-supply chain All the parts, materials, and services supplied by outside sources that are necessary to produce a product or service.

DTD (dock-to-dock) A metric that measures how long it takes raw materials or sub-components coming into a plant to be turned into finished products.

end-of-the-line inspection An inspection or check done at the end of a process. See also *judgment inspection*.

enterprise resource planning (ERP) The integration of all an organization's departments and functions onto a single computer system that can serve all those different departments' needs.

error Any deviation from a specified manufacturing or business process. Errors cause defects in products or services.

error-proofing devices Mechanical, electrical, or pneumatic devices that signal existing errors or prevent potential ones.

external processes Activities that an equipment operator can perform while the production line is still running. Compare to *internal processes*.

FIFO (first-in, first-out) A production method in which the oldest remaining items in a batch are the first to move forward in the production process.

5S's (Sort, Shine, Set in Order, Standardize, and Sustain) A method of creating a clean and orderly workplace that exposes waste and errors.

fixed costs Costs that aren't changed by production or service/sales levels, such as rent, property tax, insurance, and interest expenses. They are the costs of being in business. Compare to *variable costs*.

fixed-value method An error-proofing method that ensures the right quantity of parts is used or the right number of activities are performed.

FTT (first time through) A metric that measures the percentage of units or aspects of a service that are completed without error the first time they go through your work processes.

hard-cost savings Money that actually produces cash savings or profit increases and directly affects a company's profit-and-loss statement. Compare to *soft-cost savings*.

informative inspections An error-proofing method that provides timely information about a defect so that a root-cause analysis can be performed and process adjustments can be made before significant numbers of defects are created.

internal processes Activities that an equipment operator must perform while the production line is idle. Compare to *external processes*.

inventory Any part or product that is not immediately required for a customer order, such as excess raw materials, work in progress (WIP), and finished goods.

ITO (inventory turnover rate) A metric that measures how quickly your company sells the products you produce.

judgment inspection An error-proofing method in which a quality inspector or operator compares the final product or part with a standard. It is a type of end-of-the-line inspection.

just-in-time inventory (JIT) A method of inventory management in which small shipments of stock are delivered as soon as they are needed. JIT minimizes stocking levels.

kanban system A production-control system that uses cards or tickets as visual signals to trigger or control the flow of materials or parts during the manufacturing process.

lead time The time it takes to complete an activity from start to finish; it includes batch and process delays.

lean metrics Financial, behavioral, and core-process measurements that help you monitor your organization's progress toward achieving the goals of your lean initiative.

load balancing Finding a balance between the volume of work that your organization needs to do and your capacity.

load leveling Adjusting a production schedule to meet unexpected changes in customer demand.

location indicators Markers that show where and how much material should be kept in a specific location in a work area.

marketplace An area where materials are stocked in a supermarket system.

motion-step method An error-proofing method that involves checking to make sure actions are performed in the correct sequence.

OEE (overall equipment effectiveness) A metric that measures the availability, performance efficiency, and quality rate of your equipment.

OFLT (order-fulfillment lead time) The average time that elapses between your company's receipt of an order from a customer and when you send an invoice to your customer for the finished product or service.

one-piece flow The movement of products through the manufacturing process one unit at a time. Compare to *batch processing*.

OTD (on-time delivery) A metric that measures the percentage of units you produce that meet your customers' deadlines.

planned maintenance Maintenance activities that are performed on a set schedule. Compare to *reactive maintenance*.

PQ analysis table A tool that helps employees understand the types of products your organization produces and the volume that your customers demand. (The *P* in *PQ* stands for *products*; the *Q* stands for *quantity* of production output.)

process A series of steps or actions that produces a completed order or product.

process capacity table A tool for gathering information about the sequence of operations that make up a work process and the time required to complete each operation.

process delay The time that batches or lots must wait until the next process begins.

process route table A tool that shows the machines and equipment that are needed for processing a component or completing an assembly process. Aids in grouping your manufacturing tasks into work cells.

production smoothing Synchronizing the production of your company's different products to match your customer demand.

productivity The ratio of output to input. It provides information about the efficiency of your core processes.

pull system A production system in which goods are built only when requested by a downstream process. A customer's order "pulls" a product from the production system. Nothing is produced until it is needed or wanted downstream. Compare to *push system*.

push system A production system in which goods are produced and handed off to a downstream process, where they are stored until needed. This type of system creates excess inventory. Compare to *pull system*.

quality function deployment A structured process that provides a means to identify and carry customer requirements through each stage of product and service development and implementation. Quality responsibilities are effectively deployed to any needed activity within a company to ensure that appropriate quality is achieved.

quick changeover A method of analyzing your organization's manufacturing processes and then reducing the materials, skilled resources, and time needed for equipment setup, including the exchange of tools and dies. It allows your organization to implement small-batch production or one-piece flow in a cost-effective manner.

reactive maintenance Maintenance activities that are performed after a piece of equipment breaks. Compare to *planned maintenance*.

red-flag condition A situation in which the probability that errors will happen is high.

return on investment (ROI) Profit from an investment as a percentage of the amount invested.

root-cause analysis A process of identifying problems in an organization, finding their causes, and creating the best solutions to keep them from happening again.

RTY (rolled throughput yield) A metric that measures the probability that a process will be completed without a defect occurring.

self-inspection An inspection performed by the operator at his or her own workstation or area.

shadow board A visual control technique that uses an image of an object to show where it should be stored.

soft-cost savings Assets that are freed up so they can be used for another purpose. This contributes no positive change to a company's profit-and-loss statement. Compare to *hard-cost savings*.

source inspection An inspection that detects errors in the manufacturing process before a defect occurs in the final part or product.

standard operating procedures (SOPs) Reliable instructions that describe the correct and most effective way to get a work process done.

standard operations The most efficient work combination that an organization can put together.

standard operations combination chart A tool that enables you to study the work sequence for all your organization's work processes.

statistical process control (SPC) The use of mathematics and statistical measurements to solve an organization's problems and build quality into its products and services.

streamline To reduce the time spent in non-value-added steps, such as downtime, travel time, and inspecting or reworking materials.

successive inspection An inspection that is performed after one operation in the production process is completed, by employees who perform the next operation in the process.

supermarket system A stocking system in which materials are stored by the operation that produces them until they are retrieved by the operation that needs them. When a store is full, production stops.

symmetry When opposite sides of a part, tool, material, or fixture are, or seem to be, identical. The identical sides of a symmetrical object can be confused during an operation, resulting in errors. Compare to *asymmetry*.

takt time The total available work time per day (or shift) divided by customer-demand requirements per day (or shift). Takt time sets the pace of production to match the rate of customer demand. For example, if your customers demand 480 spark plugs per day and your production line operates 960 minutes per day, takt time is two minutes; if customers want two new contracts written per month, takt time is two weeks.

total productive maintenance (TPM) A series of methods that ensures every piece of equipment in a production process is always able to perform its required tasks so that production is never interrupted.

Traditional Cost Accounting (TCA) An accounting technique that arbitrarily allocates overhead to the products or services an organization creates. It is unable to calculate the actual cost of a product or service. Compare to *Activity-Based Costing (ABC)*.

value-added activities Tasks performed during the production of a product or service that increase its value to the customer.

value stream All the activities that a company must do to design, order, produce, and deliver its products or services to customers.

value stream map An illustration that uses simple graphics or icons to show the sequence and movement of information, materials, and actions in a company's value stream.

VA/NVA (value-added to non-value-added) ratio A metric that compares the amount of time in your work process spent on value-added activities to the amount of time spent on non-value-added activities.

variable costs Costs that vary with production or service/sales levels, such as the costs of raw materials used in the manufacturing process. Compare to *fixed costs*.

waste Any activity that takes time, resources, or space, but does not add value to a product or service.

work combination A mixture of people, processes, materials, and technology that comes together to enable the completion of a work process.

workflow The steps and motions employees take to perform their work tasks.

workflow diagram A graphic that shows your organization's current equipment layout and the movement of materials and workers during work processes.

work sequence The sequential order in which tasks that make up a work process are performed.

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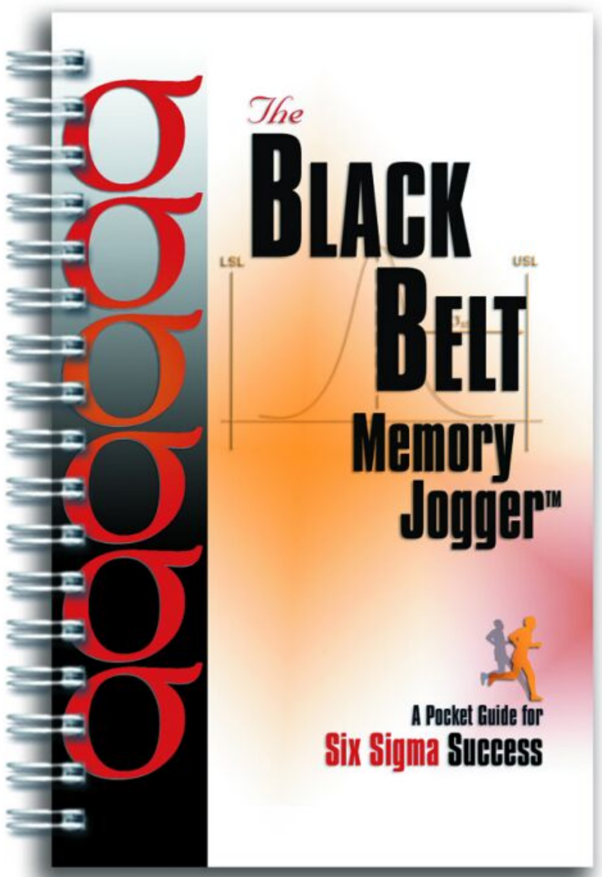

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A Pocket Guide for
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Six Sigma Academy

First Edition

GOAL/QPC

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Printed in the United States of America

First Edition 10 9 8 7 6 5 4

ISBN 1-57681-043-7

Acknowledgments

Our sincerest thanks to the people and organizations who contributed suggestions and encouragement or who gave us permission to adapt their charts, tables, and other information.

We are especially grateful to a long-time friend and supporter of GOAL/QPC, Larry Smith of Ford Motor Company, who provided the inspiration for this book.

We are indebted to the following reviewers who ensured that the finished book aligned with expectations:

Lyn Dolson Pugh, Katherine Calvert, Michael G. Thibeau, *Dow Chemical Company*; Larry R. Smith, *Ford Motor Company*; Marc Richardson, *JAE Oregon, Inc.*; Kristi Brown, *Wal-Mart*; David M. Oberholtzer, *Raytheon Company*; Richard K. Bergeron, *Seagate Inc.*

We are also grateful for those who shared with us their vision for this book:

Raj Gohil, *AT&T Corporate Quality*; Rip Stauffer, *BlueFire Partners;* Jeff Karl, *Bombadier Regional Aircraft*; C. Gregory Brown, *Citigroup;* Randy Fach, *Dove Consulting*; Kui-Sun Yim, *Ford Motor Company*; Cheryl Rienzo, *Honeywell, Inc.*; David Fogelson, *Honeywell, Inc.*; Eric Jakubowski, *Motorola, Inc.*; John Thomasson, *NCR Corporation*; Russell Soukup, *Pemstar, Inc.*; Bill Fechter, Ph.D., *Productivity Inc.*; Jay P. Patel, *Quality & Productivity Solutions, Inc.*; Allen C. Rothman, *Quad Tech, Inc.*; Lynda Owens, Neal Mackertich, *Raytheon Company*; Swaminathan Balachandran, *University of Wisconsin–Platteville.*

Foreword

Six Sigma programs have made tremendous contributions to many organizations worldwide, and we at GOAL/QPC anticipate that the long-term benefits will accrue as more organizations learn and apply Six Sigma.

However, as Six Sigma becomes more commonplace, it will be accompanied by increased pressure to quickly train Black Belts and to produce results. For some prospective Black Belts, the learning challenge will be daunting and the post-training performance expectations even more so.

To help support new and current Black Belts, we decided to create a Memory Jogger specifically for their needs. We partnered with Six Sigma Academy and melded their extensive knowledge and experience in Six Sigma tools and methods with GOAL/QPC's skill in producing Memory Jogger™ pocket guides. In preparing this guide, we are assuming that users are familiar with DMAIC processes, the basics of quality management, and the basic quality tools found in *The Memory Jogger™ II*.

The Black Belt Memory Jogger™ serves double duty as a training document for new Black Belts and a ready reference to support their real-world performance.

With the help of many reviewers, the experts and practitioners who worked on this project have assembled the necessary information to support successful Black Belt performance. We trust you will agree.

Bob Page
GOAL/QPC

Table of Contents

Introduction

What is Six Sigma?

The Six Sigma methodologies are a business philosophy and initiative that enables world-class quality and continuous improvement to achieve the highest level of customer satisfaction. Metrics are established that align an organization's strategic goals and values to that of their customer's needs and expectations.

Sigma (σ) represents a unit of measurement that designates the distribution or spread about the mean (average) of a process. In business, a sigma value is a metric that represents how well a process is performing and how often a defect is likely to occur. The higher the sigma value, the less variation and fewer defects the process will have. Six Sigma is the new standard of excellence at only 3.4 defects per million opportunities (DPMO).

How does it work?

The Six Sigma philosophy uses data and statistical tools to systematically improve processes and sustain process improvements. Process metrics are evaluated based on a comparison of average and variation to performance specifications or targets.

The methodology is a project-focused approach consisting of five phases: Define, Measure, Analyze, Improve, and Control. Projects are selected and *Defined* from business, operational, and customer needs, based on their linkage to executive strategies. In the *Measure* phase, tools are applied to validate the measurement system and to characterize the process. In the *Analyze* and *Improve* phases, sources of variation are identified, a statistical relationship between the process input and output variables is established, and the process performance is optimized. The *Control* phase applies traditional and statistical tools to sustain process improvements. Emphasis is placed on controlling the key process inputs to consistently achieve key process outputs.

The DMAIC Model

What is it?

The DMAIC model is a set of tools outlined in five phases that are used to characterize and optimize both business and industrial processes. Each project must complete the five phases in chronological order.

Define Phase

In the Define phase, the customer needs are stated and the processes and products to be improved are identified.

Steps	Activities/Tools	Output(s)
Create problem statement	• Define process to improve • Define project objectives • Identify project stakeholders • Identify customers	• Problem statement • Project scope • Project goals
Identify CTQs	• CT Trees	• Identified customer needs
Define performance standards	• Identify performance measures • Financial analysis • High-level process mapping	• Gap analysis • Business impact (project savings) • Project definition • Project charter • Project plan/ timeline • High-level process map • Definition of performance measures

Measure Phase

The Measure phase determines the baseline and target performance of the process, defines the input/output variables of the process, and validates the measurement systems.

Steps	Activities/Tools	Output(s)
Understand process and validate measurement system	• Process-map the as-is process • Identify process inputs/outputs • Collect data • Evaluate measurement system of process y's	• Detailed process map • Identified process output variables (POV) – (y's) and their measurements • Identified process input variables (PIV) – (x's) • Validated performance data • Measurement system capability on y's • Data collection/ sampling plan
Determine process capability	• Control charts on process y's • Capability analysis • Graphical techniques	• Baseline control charts • Baseline capability • DPMO • Z value
Finalize performance objectives	• Cause and effect analysis • Create FMEA • Review of project goals and plan	• Revised project goals • Quantified project objectives • Validated financial goals • Revised project plan • Cause and effect relationships • Prioritized risk

Analyze Phase

The Analyze phase uses data to establish the key process inputs that affect the process outputs.

Steps	Activities/Tools	Output(s)
Identify sources of variation	• Detailed process map • Brainstorming • Fishbone diagram • Cause & Effect Matrix • FMEA • SPC on x's and y's • MSA on x's	• Identified sources of variation • Identified potential leverage variables (KPIVs) • Updated process map • Updated FMEA
Screen potential causes	• Graphical analysis • Hypothesis testing • Multi-Vari analysis • Correlation and regression analysis	• Potential x's critical to process performance • Identified improvement opportunities • Data on KPIVs • Statistical analysis of data

Improve Phase

The Improve phase identifies the improvements to optimize the outputs and eliminate / reduce defects and variation. It identifies x's and determines the $y = f(x)$ relationship, and statistically validates the new process operating conditions.

Steps	Activities/Tools	Output(s)
Determine variable relationship $y = f(x)$	• Designed experiments • Regression analysis • ANOVA • Simulation	• Relationships between x's and y's • KPIV settings for optimum process outputs and minimum output variation
Establish operating tolerances	• Establish relationships between x's and y's • Use optimum settings for x's • Determine new process capability • Cost/benefit analysis	• Optimum robust settings for x's with tolerances • Updated project plan • Established implementation plan
Confirm results and validate improvements	• Confirmation experiments • Process maps • MSA • Control charts • Process capability • Corrective actions	• Updated process maps, FMEA, data collection • Pilot run • Validated measurement systems after improvements (x's and y's) • Improved capability

Control Phase

The Control phase documents, monitors, and assigns accountability for sustaining the gains made by the process improvements.

Steps	Activities/Tools	Output(s)
Redefine process capabilities x's and y's	• Control plan SPC on x's and y's • Capability analysis	• Control plan • Control charts • DPMO • Z
Implement process control	• Mistake proofing • Standard procedures • Accountability audits • Responsibility audits • Finalize transition to process owner • FMEA • Preventive maintenance • Gauge control plans	• Validated control process • Sustained performance • Monitoring plan • Recalculated FMEA RPN • System changes to institutionalize improvement
Complete project documentation	• Financial validation • Team meeting with stakeholders and customer • Project tracking completion • Identify replication of project results opportunities	• Lessons learned/ best practices • Communicated project success • Project report • Executive summary • Final deliverables • Customer feedback

Roles and Responsibilities

Why is understanding roles and responsibilities important?

Prior to deployment, during deployment, and in transition to the organization, there are critical roles and responsibilities that ensure Six Sigma methodologies become ingrained in the business. Understanding who is responsible for each activity will allow for an effective deployment.

Executives

- Create the vision for the Six Sigma initiative.
- Define the strategic goals and measures of the organization.
- Establish the business targets.
- Create an environment within the organization that will promote the use of the Six Sigma methodology and tools.

Senior Deployment Champion

- Is responsible for the day-to-day management of Six Sigma throughout the entire organization.
- Designs the Six Sigma infrastructure and support systems (training, project approvals, human resources, reporting systems, etc.)
- Uses performance goals to get business unit leaders on board.
- Reports to and updates the executives on the progress of deployment.
- Acts as a liaison between the executives and deployment champions.
- Works with deployment champions to develop a communication plan for the organization.

Deployment Champion

- Is responsible for the deployment of Six Sigma within his/her division or business unit.
- Works with the leaders of the division or business unit to determine their goals and objectives and ensure that they are aligned with the executives.
- Conducts a Critical To flowdown to identify areas of opportunities that are aligned with the business goals.
- Facilitates the identification and prioritization of projects.
- Establishes and executes training plans.
- Develops a communication plan for the division or business unit.
- Reports the deployment status of the division or business unit to the senior deployment champion.
- Selects the project champions.
- Removes barriers for the team.

Project Champion

- Selects and mentors Black Belts.
- Leads in project identification, prioritization, and defining the project scope.
- Removes barriers for Black Belts and aligns resources.
- Works with deployment champions to implement the Six Sigma infrastructure.
- Communicates progress of Six Sigma projects to the deployment champion and process owners.

Master Black Belt

- Is an expert on Six Sigma tools and concepts.
- Trains Black Belts and ensures they are properly applying the methodology and tools.
- Coaches and mentors Black Belts and Green Belts.

- Maintains the training material and updates it if necessary.
- Works high-level projects, many of which are across divisions or business units.
- Assists champions and process owners with project selection, project management, and Six Sigma administration.

Black Belt

- Is responsible for leading, executing, and completing DMAIC projects.
- Teaches team members the Six Sigma methodology and tools.
- Assists in identifying project opportunities and refining project details and scope.
- Reports progress to the project champions and the process owners.
- Transfers knowledge to other Black Belts and the organization.
- Mentors Green Belts.

Process Owner

- Is a team member.
- Takes ownership of the project when it is complete.
- Is responsible for maintaining the project's gains.
- Removes barriers for Black Belts.

Green Belt

- Is trained in a subset of the Six Sigma methodology and tools.
- Works small scope projects, typically in his/her respective work area.
- Can be an effective team member on a Black Belt team.

Finance Champion

- Estimates and certifies project savings.
- Establishes clear criteria on hard and soft savings.
- Works with deployment champions to identify potential project opportunities.
- Assigns a finance representative to each Black Belt team.

Information Technology Champion

- Ensures computer and software resourcing.
- Works with Black Belt teams to access data from existing databases.
- Works with Black Belt teams to develop an electronic project tracking system to collect, store, analyze, and report project data.
- Provides training on the project tracking system.
- Develops a reporting system to keep executives and project champions informed about progress in meeting goals and targets.

Human Resources Champion

- Identifies roles and responsibilities for Master Black Belts, Black Belts, and Green Belts.
- Works with the project champions to develop a Master Black Belt, Black Belt, and Green Belt selection process.
- Develops a career path transition process for Master Black Belts and Black Belts.
- Works with the senior deployment champion and project champions to determine rewards and recognition for Master Black Belts, Black Belts, Green Belts, and teams.

Project Management

(**Note:** An in-depth discussion of the components of project management is beyond the scope of this book. For a complete description, please refer to the *Project Management Memory Jogger™.)*

Why use it?

Project management:

- Defines expected timelines and the project scope.
- Focuses time and resources to meet the customer requirements for a project.
- Reduces duplication of effort.
- Identifies problem areas and risk.
- Serves as a communication tool.

What does it do?

It assigns roles, responsibilities, and timing of deliverables to allow each person to know what his or her tasks are and when they are due. It also provides the project manager with a way to monitor progress in order to take action when appropriate.

How do I do it?

There are four basic phases in project management: 1) Creating a project charter, 2) Creating a project plan, 3) Executing and monitoring the plan, and 4) Completing (closing out) the project.

Project Charter

Why do it?

A project charter defines the customer needs, project scope, project goals, project success criteria, team members, and project deadlines.

How do I do it?

1. **Create a problem statement that describes the project.**
2. **Identify the customer needs.**
3. **Identify the project goals, project success criteria, and final deliverable for the project.**
4. **Identify the roles and responsibilities of team members.**
5. **Identify the stakeholders and resource owners for project approval.**

Project Plan

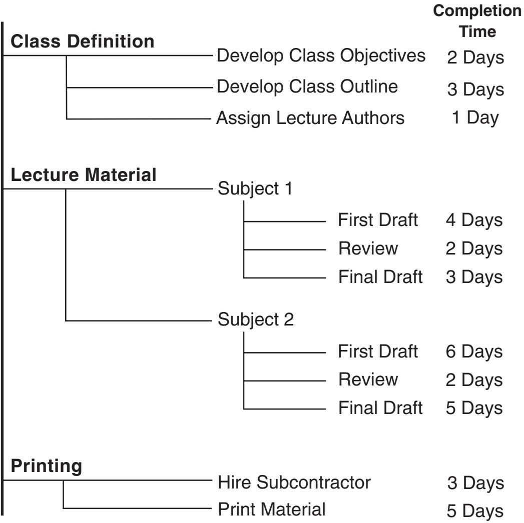
Why do it?

The project plan identifies all the work to be done, who will do the work, and when the work will get done.

How do I do it?

1. **Identify the work to be done.**
    - Use a work breakdown structure (WBS) to identify the work to be done. The WBS is a hierarchical grouping of project tasks that organizes and defines the total project work.

A Work Breakdown Structure for the Development of an Educational Course



2. Assign resources and estimate the time duration.

- For each task identified in the WBS, resources must be assigned and a time duration estimated. To document these activities, use an accountability matrix. The accountability matrix documents who is accountable for a particular task, who's input is required to complete a task, who is required to review the task, and who is required to sign-off on the task completion.

An Accountability Matrix for the Educational Course WBS

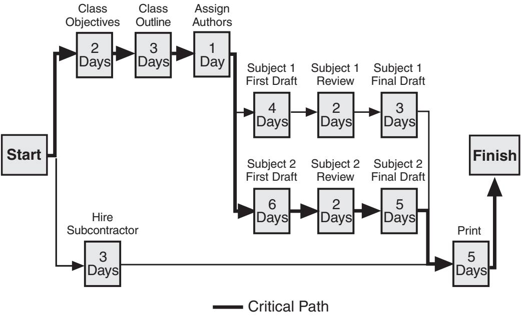
			Resources		
ID	**Task**	**Duration (Days)**	**Tim**	**Alex**	**Julia**
1	Class Definition			A	
1.1	Develop Class Objectives	2	A	R	I
1.2	Develop Class Outline	3	A	R	I
1.3	Assign Lecture Authors	1		A	
2	Lecture Material			A	
2.1	Subject 1		A		
2.1.1	First Draft	4	A		I
2.1.2	Review	2	A	R	
2.1.3	Final Draft	3	A	S	I
2.2	Subject 2				A
2.2.1	First Draft	6	I		A
2.2.2	Review	2		R	A
2.2.3	Final Draft	5	I	S	A
3	Printing			A	
3.1	Hire Subcontractor	3		A	
3.2	Print Material	5	I	A	I

Key	
A	Accountable
R	Review Required
I	Input Required
S	Sign-off Required

3. **Develop a project schedule.**

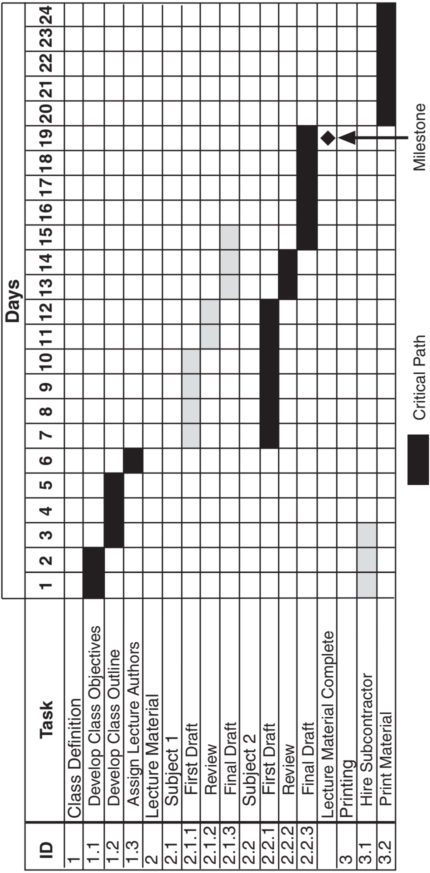
   - Identify the critical path of the project on an Activity Network Diagram. The critical path is the shortest possible time to complete the project from the first task to the last task.

An Activity Network Diagram for the Educational Course Development



   - Draw a Gantt Chart displaying the project tasks and their duration. Add appropriate milestones in the Gantt Chart.

Team-Defined Milestones and Gantt Chart from the Educational Course Activity Network Diagram



Project Execution and Monitoring

Why do it?

Once the project plan has been completed, it is time to execute the project and monitor its progress. It is important to monitor the project to ensure timely deliverables that stay within budget.

How do I do it?

Executing the project is doing the tasks assigned. Monitoring the project is done by holding regular team meetings to update the progress of the activities. At these meetings, the people accountable for each task should give a "percent complete" status of their particular task. Any gaps or risks in completing the program should be identified at this time and recovery plans put in place. An action item list for the project should be developed and the schedule should be updated to show any delays in task completion or milestone dates.

Project Close Out

Why do it?

Formally closing out the project ensures that future teams will benefit from the documented lessons learned so that they can duplicate successes and avoid problems the team encountered.

How do I do it?

1. **Hold a team meeting with the customers and stakeholders of the project to solicit feedback on opportunities for improvement and to identify things that were done well.**

2. **Develop and document lessons learned.**
   - The team should review the results from the team meeting and its own personal experience, and document the lessons learned.
3. **Create a project report.**
   - The team should create a report that summarizes the team's activities on the project. The report should include all the information from the project charter, an executive summary on the project, the lessons learned on the project, a description of the final deliverable, and the customers' feedback. The report should be archived and a copy should be made available to all those involved and affected by the project.

Critical To Flowdown

Why use it?

During the Define phase, project champions and Black Belts use Critical To Trees (CT Trees) and Critical To Matrices (CT Matrices) as tools to define DMAIC projects. The CT Tree is used as a method to analyze customer requirement flowdown to ensure that what the organization is working on is critical to its business and its customers and strikes a balance between both. The CT Matrix identifies customer requirements and links these requirements in a matrix fashion to those organizational processes most likely to impact them. (Both of these tools consider customers to be either the external or internal users of the product or service.)

What does it do?

The CT Tree is a tool that translates needs considered vital by the customer into product and service characteristics, and links these characteristics to organizational processes. The CT Matrix is a simplified version of a Quality Function Deployment (QFD). A single Black Belt project could employ CT Trees and CT Matrices at various levels within a process.

Before creating a CT Tree or CT Matrix, certain terms to describe characteristics in these tools must be defined:

- *Critical To Satisfaction* (CTS) characteristics relate specifically to the satisfaction of the customer. The customer will typically define satisfaction in one of three ways:
    1. *Critical To Quality* (CTQ) characteristics are product, service, and/or transactional characteristics that significantly influence one or more CTSs in terms of quality.

   2. *Critical To Delivery* (CTD) characteristics are product, service, and/or transactional characteristics that significantly influence one or more CTSs in terms of delivery (or cycle).
   3. *Critical To Cost* (CTC) characteristics are product, service, and/or transactional characteristics that significantly influence one or more CTSs in terms of cost.

- *Critical to the Process* (CTP) characteristics are process parameters that significantly influence a CTQ, CTD, and/or CTC.

For the equation $y = f(x_1, x_2, \ldots x_n)$, the CTQ, CTD, or CTC characteristics represent the dependent variable (y), and the CTP characteristics represent the independent variables (x's).

The CTQ, CTD, and CTC are "opportunities for nonconformance" that must be measured and reported, while the CTP represents "control opportunities."

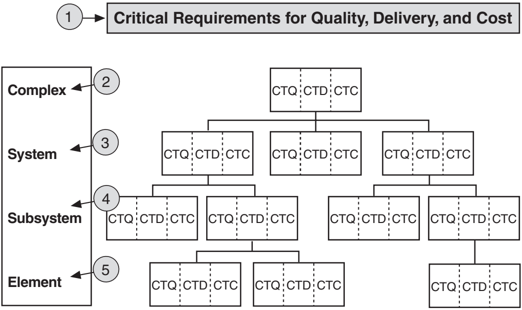
How do I do it?

There are two types of trees or flowdowns that need to be created to strike a balance between the business and the customer: *process trees* and *product trees*.

- A *process tree* is a breakdown of the organization's engineering, manufacturing, service, and transaction processes. CTPs are identified at the lowest level of this tree.
- A *product tree* is a hierarchical breakdown of the organization's product or service, which allows a visualization of the CTQ, CTD, and CTC characteristics at each level of the hierarchy.

A typical CTX product tree is shown in the following figure. The numbers in the text that follows correspond to the numbers in circles in the graphic.

A CTX Product Tree or Flowdown



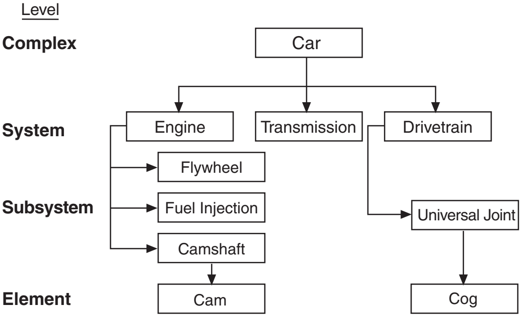
1. Critical requirements for quality, delivery, and cost are translated from the CTS characteristics.
2. The complex level is the first level of the product tree and describes the final product or service that is delivered to the customer. CTQs, CTDs, and CTCs can be found at this level and are usually expressed as a function of the immediate lower level characteristics: CTQ-complex = f (CTQ-system$_1$, ... CTQ-system$_n$).
3. The system level is a more detailed breakdown of the complex level. CTQs, CTDs, and CTCs can be found at this level and are usually expressed as a function of the immediate lower level characteristics: CTQ-system = f (CTQ-subsystem$_1$, ... CTQ-subsystem$_n$).
4. The subsystem level is a more detailed breakdown of the system level. CTQs, CTDs, and CTCs can be found at this level and are usually expressed as a function of the

immediate lower level characteristics: CTQ-system = f (CTQ-element$_1$, ... CTQ-element$_n$).

5. The element level is the lowest level of the tree. Its components are not divisible. CTQs, CTDs, and CTCs can be found at this level.

The size of the tree is dependent on the complexity of the product or service (e.g., a spark plug is less complex than a car and would therefore have a less complex CT Tree). Described in the following figure is a tree that looks at the product a business might sell to a customer.

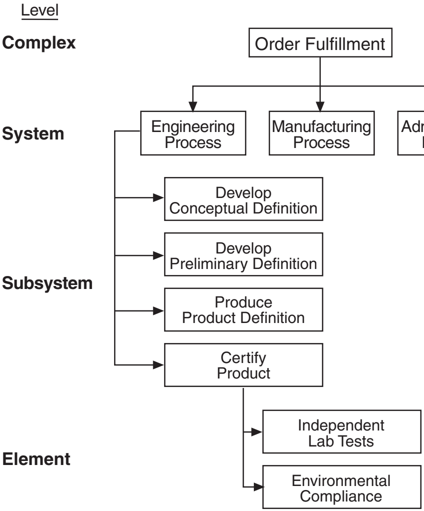
Product Flowdown



A given product or service at any level of the hierarchy in this tree can have quality, delivery, and/or cost issues that concern customers. Within the hierarchy, the organization must consider whether it is satisfying those customer needs.

A CTX process tree for the major processes that support the engineering, manufacturing, marketing, and sales of this car can also be created, as described in the figure on the next page.

Process Flowdown



This process tree will help identify the individual x's that can potentially impact the individual y's of a product.

To determine which product and/or process needs the most attention the organization will create a CT Matrix. The CT Matrix, like the CT Tree, is developed by the project champion and the Black Belt, together with a team that collectively has process/product knowledge and, to the greatest extent possible, an understanding of the voice of the customer. It is owned by the product or process owner.

Once the product tree has been developed and customer requirements (CTS) identified, the organization can use a CT Matrix to determine which processes are most likely to impact those CTS requirements, as shown in the figure on the next page.

A CT Matrix

Product Tree Complex Level Process Tree Subsystem Level	Needs to achieve 35 mpg highway 27 mpg city	Needs to hold six occupants comfortably	Needs to convert to all-wheel drive on the fly	Needs to cost under $40K	Must be available July	Must have superior exterior finishing
Engineering System						
• Develop conceptual definition	✔	✔	✔	✔	✔	✔
• Develop preliminary definition	✔	✔	✔	✔	✔	✔
• Produce product definition	✔	✔	✔	✔	✔	✔
• Certify product	✔				✔	
• Support product development						
• Manage project					✔	
Manufacturing System						
• Bid preparation						
• Program or contract start-up						
• Technical data preparation						
• Projection of first and subs	✔			✔	✔	✔
• Testing and commissioning					✔	
Customer Support						
• Product management						
• Manage customer						
• Contracts						
• Spares/tech pub/training				✔	✔	
• Maintenance engineering						
• Completion center				✔	✔	✔
• Aviation service						
Administrative Process						
• Finance/budget/billing						
• Human resources relations						
• Strategic plan and communication						

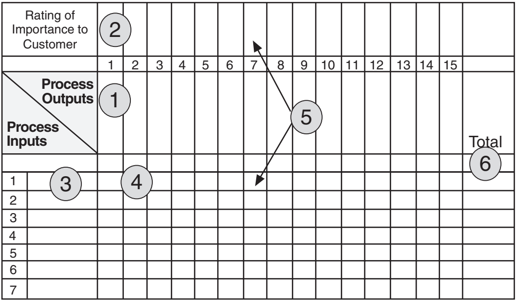
In this example matrix, it appears that the greatest area for opportunity to effect change is in the Engineering System. The team then could collect more detailed information about the individual cells within this matrix to help narrow the focus.

No matter the complexity of the product or process, these top-level tools assist the project champion and Black Belt in continually narrowing the focus. More detailed information about the individual cells within the matrix could be collected until the project is scoped to a manageable level. High-level process maps are created, followed by more detailed process maps as the input variables become more key and additional granularity is required. (Process maps are explained in more detail in a subsequent chapter in this book.)

> ***Tip*** An important concept to remember is to avoid "drilling down" too quickly into the details of the process and stay at the highest process level possible for as long as possible.

At this point, the Black Belt still needs to determine where the greatest opportunity for improvement is in the process, by collecting more data about the individual process steps. Subsequently, the Black Belt will need to create a Cause & Effect (C&E) Matrix, as shown in the following figure. The numbers in the graphic correspond to the steps (on the next page) required to complete this matrix.

A C&E Matrix



To complete this matrix:

1. The y's from the process identified from the previous CT Matrix are placed across the columns of the C&E Matrix.
2. The y's are ranked relative to one another on a scale of 1-10 with respect to their importance to the customer.
3. The process steps or CTXs obtained from the process mapping exercise are placed down the first column of the matrix, establishing the identity of each row. Depending on the number of process inputs, starting at a higher level (of process steps) is much more efficient.
4. The steps or CTXs are compared to the y's of the process by a force-ranking on the following (or similar) scale: 0, 1, 4, and 9. The forced ranking is done to prioritize the CTXs. In this step, the team should ask, "If a particular x was changed, would it significantly impact y, either positively or negatively?" If the team considers that the impact would be significant, then a ranking of 9 is given. If the team does not think the y will be impacted, then a score of 0 or 1 will be appropriate. If one person wants to give a ranking of 9 and the other team members want to give a ranking of 1, the team should not take the average, but should discuss the situation to determine what knowledge the person who wants to rank a 9 has that the other team members do not have.
5. For each row, the sum-product is calculated by multiplying the cell rating (from step 4) by the importance rating for the y in that column (from step 2). The products across each row are added together and stored in the last column, titled Totals (6).
6. The Totals column is then sorted in descending order. The values with the highest totals are those CTXs that are most likely to impact the project.

C&E Matrix Example:

A Black Belt was assigned to a team with the Engineering Systems process owners/representatives. Their goal was to apply the C&E Matrix to determine the initial "process" focus of a Black Belt project within the larger Engineering Systems process. To ensure that the team was cross-functional, the product development and management teams from each facet of the organization were also represented. The team started with previously created CT Trees and a CT Matrix. Each member had also conducted a review of the new product under development and reviewed data collected on previous new product introductions in their respective areas. They decided to create a C&E Matrix based on the current process performance and the relationship between customer requirements of this particular product and the Engineering Systems process steps.

The Team's C&E Matrix

Rating of Importance to Customer		6	9	9	10	10	7	
		1	2	3	4	5	6	
Process Inputs (Steps)		Needs to achieve 35 mpg highway 27 mpg city	Needs to hold six occupants comfortably	Needs to convert to all-wheel drive on the fly	Needs to cost under $40k	Must be available July 2003	Must have superior exterior finish	**Total**
2	Preliminary Design (D)	9	9	9	9	9	④	424
3	Product Definition - Optimize (O)	9	4	9	9	4	4	329
6	Manage Project	4	1	4	⑨	⑨	4	277
5	Support Production Development	4	4	4	4	1	⑨	209
1	Conceptual - Identify (I)	1	4	4	1	9	4	206
4	Certify Product - Validate (V)	4	1	4	4	4	1	156
Total Column Score		186	207	306	360	360	182	

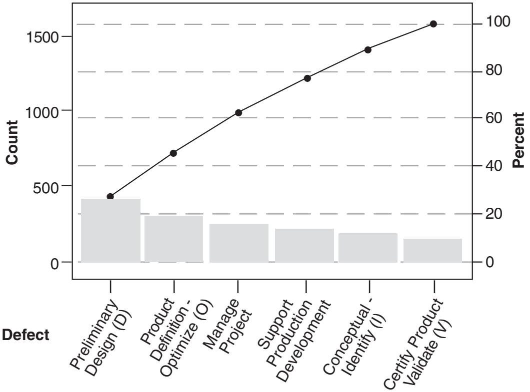
CTSs were taken from the CT Matrix and placed along the top of the C&E Matrix. All six of these CTSs were then assigned a ranked score or rating from 1 to 10, based on the importance to the customer. The team noticed that these importance ratings received rankings from 6 through 10. The CT Matrix also identified the major process steps, 1 through 6, of the Engineering Systems process. (This served as their high-level process map.) These process steps then served as the process inputs down the left side of the matrix. Each step was ranked on the 0,1,4,9 scale to ascertain the linkage between the voice of the process (VOP), the process steps, and the voice of the customer (VOC) or CTSs. (The VOP are the "causes" and the VOC is the "effect"; hence the "C&E" Matrix.)

(To narrow the focus, another C&E Matrix was then created to link the customer requirements to the process steps. This is a mid-level application of the C&E Matrix because it is dealing with process steps vs. more-detailed process inputs from each step. Subsequent C&E Matrices can be created after one particular process or area is highlighted as having the greatest impact on the customer requirements.)

The team assessed the linkages based on collective experience and data. Considerations were based on existing and proposed process capability and technology roadmaps. For example, the "Preliminary Design Efforts" were scored lower (4) for "superior exterior finish" because this was an existing capability for the organization. The team was more concerned with maintaining exterior finish in the production process and therefore assigned a score of 9 to "Support Production Development." Also, the management team was much more concerned with managing total cost and schedule as it pertained to the "Manage Project" process step. Upon completion of the rankings, the totals were calculated and the steps were sorted in descending order of the total scores.

A Pareto Chart was created based on the total scores for each process step, showing that the Preliminary Design step appeared to be the most critical step in the process, because it related to all of the customer requirements identified on the matrix. This process step contributes 26.5% of the total variation or risk to the development of this new product. Therefore, the first Black Belt project to be defined should concentrate efforts in this area.

A Pareto Chart of the C&E Matrix Results



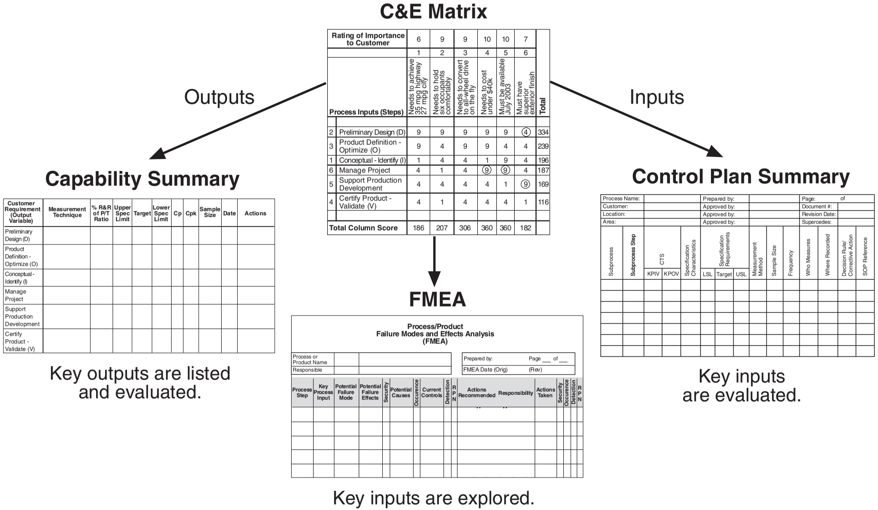
Count	424	329	277	209	206	156
Percent	26.5	20.5	17.3	13.1	12.9	9.7
Cum %	26.5	47.0	64.3	77.4	90.3	100.0

A recommended cross-validation is to evaluate the total column scores in the matrix for each customer requirement. These scores are calculated similarly to the row totals. The column scores represent the weighted sums of the CTSs as they relate to the entire Engineering Systems process. Comparing these totals to the ratings assigned to their respective CTS ensures that the process gives fair weight and consideration to each of the customer requirements relative to the assigned ratings. A discrepancy would indicate either a significant disconnect in the process, unrealistic rankings of the process steps, or missing steps not included in the matrix. As an extreme example, a column totaling zero would indicate that none of the listed CTXs had any perceived effect on the CTY of that column.

Next Steps: Links to Other Tools

The team's next step would be to create a more detailed process map of the Preliminary Design process. The process map will include inputs and outputs of each detailed step. A subsequent C&E Matrix can then be conducted on the detailed process steps or process inputs from the detailed process map. The team will then evaluate the process inputs associated with these steps on an FMEA. The FMEA will be completed with the comprehensive list of inputs.

Links to Other Tools



C&E Matrix

Rating of Importance to Customer		6	9	9	10	10	7	
		1	2	3	4	5	6	
Process Inputs (Steps)		Needs to achieve 35 mpg highway 27 mpg city	Needs to hold six occupants comfortably	Needs to convert to all-wheel drive on the fly	Needs to cost under $40k	Must be available July 2003	Must have superior exterior finish	**Total**
2	Preliminary Design (D)	9	9	9	9	9	④	334
3	Product Definition - Optimize (O)	9	4	9	9	4	4	239
1	Conceptual - Identify (I)	1	4	4	1	9	4	196
6	Manage Project	4	1	4	⑨	⑨	4	187
5	Support Production Development	4	4	4	4	1	⑨	169
4	Certify Product - Validate (V)	4	1	4	4	4	1	116
Total Column Score		186	207	306	360	360	182	

Capability Summary

Customer Requirement (Output Variable)	Measurement Technique	% R&R of P/T Ratio	Upper Spec Limit	Target	Lower Spec Limit	Cp	Cpk	Sample Size	Date	Actions
Preliminary Design (D)										
Product Definition - Optimize (O)										
Conceptual - Identify (I)										
Manage Project										
Support Production Development										
Certify Product - Validate (V)										

Key outputs are listed and evaluated.

FMEA

Process/Product
Failure Modes and Effects Analysis
(FMEA)

Process or Product Name		
Responsible		

Prepared by:	Page ___ of ___
FMEA Date (Orig)	(Rev)

Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	Security	Potential Causes	Occurence	Current Controls	Detection	RPN	Actions Recommended	Responsibility	Actions Taken	Security	Occurence	Detection	RPN

Key inputs are explored.

Control Plan Summary

Process Name:	Prepared by:		Page: of
Customer:	Approved by:		Document #:
Location:	Approved by:		Revision Date:
Area:	Approved by:		Supercedes:

Subprocess	Subprocess Step	CTS		Specification Characteristics	Specification Requirements			Measurement Method	Sample Size	Frequency	Who Measures	Where Recorded	Decision Rule/ Corrective Action	SOP Reference
		KPIV	KPOV		LSL	Target	USL							

Key inputs are evaluated.

Each tool is applied with greater granularity until the potential critical inputs or x's are identified. The results of the C&E Matrix exercise are used in the FMEA exercise. The team will strategically "drill down" into the various levels of the process, from the complex level down to the element level. The CTXs that are identified as having high values in the CT Matrix are the potential critical x's. Data should be collected around these x's to validate their significance.

The process output variables from the C&E Matrix should drive additional action to complete capability studies on the y's, including measurement system analysis. (Measurement systems analysis is discussed in greater detail in a subsequent chapter of this book.) For every input that has a high impact on the CTYs of interest on the C&E matrix and/or FMEA, an initial control plan could be developed; subsequent action on capabilities on the x's may be postponed until the completion of the FMEA.

Basic Statistics

Why use it?

Once facts or data have been classified and summarized, they must be interpreted, presented, or communicated in an efficient manner to drive data-based decisions. Statistical problem-solving methods are used to determine if processes are on target, if the total variability is small compared to specifications, and if the process is stable over time. Businesses can no longer afford to make decisions based on averages alone; process variations and their sources must be identified and eliminated.

What does it do?

The Measure Phase involves designing data collection plans, collecting data, and then using that data to describe the process.

Descriptive statistics are used to describe or summarize a specific collection of data (typically samples of data). Descriptive statistics encompass both numerical and graphical techniques, and are used to determine the:

- Central tendency of the data.
- Spread or dispersion of the data.
- Symmetry and skewness of the data.

Inferential statistics is the method of collecting samples of data and making inferences about population parameters from the sample data.

Before reviewing basic statistics, the different types of data must be identified. The type of data that has been collected as process inputs (x's) and/or outputs (y's) will determine the type of statistics or analysis that can be performed.

Selecting Statistical Techniques

		Outputs	
		Attribute	Variable
Inputs	Attribute	Proportion tests, Chi-square	t-test, ANOVA, DOE, Regression
	Variable	Discriminant analysis, Logistic regression	Correlation, Multiple regression

The two classifications of data types are variable or attribute. Another way to classify data is as discrete or continuous.

Continuous data:

- Has no boundaries between adjoining values.
- Includes most non-counting intervals and ratios (e.g., time).

Discrete data:

- Has clear boundaries.
- Includes nominals, counts, and rank-orders, (e.g., Monday vs. Friday, an electrical circuit with or without a short).

Data Type Classifications

	Variable	**Variable Binary**	**Attribute Binary**	**Attribute > 2 Categories**
Discrete	Ordinal or rank-orders that get treated as an interval scale (i.e., day of week, hour of the day, age in years, counts (integers), income, proportions)	Binary with a value rank or order (i.e.,good/bad, on-time/not on-time, pass/fail)	Binary without a value rank (i.e., male/female, heads/tails coin toss)	Nominal or categorical (i.e., phone numbers, primary colors, eye color, method A,B,C, or D)
Continuous	Ratio and interval-type data (i.e.,temperature scale, weight, length, time, wavelength)		Cannot exist	

Black Belts should strive to collect continuous, variable data to enable straightforward descriptive and inferential statistics.

How do I do it?

Measures of Central Tendency

There are three measures of central tendency: the mean, the median, and the mode.

- The *mean* (μ) is the average of a set of values. The mean of a population can be calculated using the formula:

$$\mu = \frac{\sum_{i=1}^{N} x_i}{N} = \frac{x_1 + x_2 + x_3 + \ldots + x_N}{N}$$

N = total number of data points in the population

$$\sum_{i=1}^{N} = \text{Sum all values from the first to last}$$

Examples:

Average Days Late: $\frac{1 + 2 + 3 + 4 + 5}{5} = 3.0$

Inspection (Pass/Fail): $\frac{0 + 0 + 1 + 1}{4} = 0.5$

- The *median* is the midpoint in a string of sorted data, where 50% of the observations or values are below and 50% are above. If there are an even number of observations, it is the average of the two middle numbers.

Tip Order the data from low to high values when determining the median. This will make it easier to select the middle observation.

Examples:

For the odd number of observations 1, 2, 3, 4, 5, 6, 7, the median is 4. For the even number of observations 1, 2, 3, 4, 5, 6, 7, 8, the median is 4.5.

- The *mode* is the most frequently occurring value in a data set. For example, in the data set 1, 2, 3, 3, 5, 7, 9, the mode is 3.

Measures of Spread

Measures of spread include the range, the deviation, the variance, and the standard deviation.

- The *range* is the difference between the largest and smallest observations in a data set.

Range = maximum observation – minimum observation

For the data set 1,2,3,3,5,7,9, the range is 9-1 = 8.

- The *deviation* is the distance between a data point and the mean.

$$\text{Deviation} = (X-\mu)$$

In the example 1,2,3,3,5,7,9, the mean is (1+2+3+3+5+7+9)/7 = 30/7 = 4.29, and the deviation of the data point 9 is (9 - 4.29) = 4.71.

- The *variance* is the average squared deviation about the mean. The squared deviation of a single point is calculated by subtracting it from the mean and squaring the difference.
- The *standard deviation* is the square root of the average squared deviation about the mean (i.e., the square root of the variance). The standard deviation is the most commonly used measurement

to quantify variability and will be in the same units as the data collected. The formula to calculate the standard deviation in a population is:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N}}$$

To determine the population standard deviation for the data set 1, 2, 3:

X	μ	X – μ	(X – μ)^2
1	2	– 1	1
2	2	0	0
3	2	1	1
$\sum = 6$			2
N = 3			
μ = 2			

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N}}$$

$$\sigma = \sqrt{\frac{(1-2)^2 + (2-2)^2 + (3-2)^2}{3}}$$

$$\sigma = \sqrt{0.667} = 0.8167$$

The variance for a sum of two independent variables is found by adding both variances. The standard deviation for the total is the square root of the sum of both variances.

If σ_1^2 = variance of variable 1, and

σ_2^2 = variance of variable 2, then

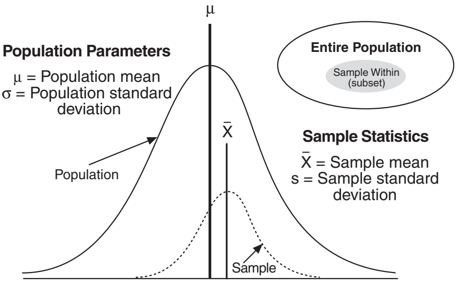
$\sigma_T^2 = \sigma_1^2 + \sigma_2^2$ and

$\sigma_T = \sqrt{\sigma_1^2 + \sigma_2^2}$

Population vs. Sample

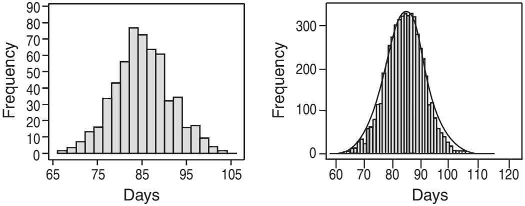
A population is every possible observation or census, but it is very rare to capture the entire population in data collection. Instead, samples, or subsets of populations as illustrated in the following figure, are captured.

Populations and Samples



A statistic, by definition, is a number that describes a sample characteristic. Information from samples can be used to "infer" or approximate a population characteristic called a parameter. (More information about using samples to infer population parameters can be found in the chapter on confidence intervals in this book.)

Sample Statistics Approximate the Population Parameters



Sample Statistics

$\bar{X}$ = 84.99
s^2 = 34.57
s = 5.88
n = 600

Population Parameters

μ = 85.06
σ^2 = 36.53
σ = 6.04
N = 5,000

Data is obtained using samples because the entire population may not be known or may be too expensive to measure. Descriptive statistics can apply to any sample or population; however, the equations are unique for each.

Population And Sample Equations

Sample mean
n = A subset of the population

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{x_1 + x_2 + x_3 + \ldots + x_n}{n}$$

Sample standard deviation

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{(n-1)}}$$

Population mean
N = Every member of the population

$$\mu = \frac{\sum_{i=1}^{N} x_i}{N} = \frac{x_1 + x_2 + x_3 + \ldots + x_N}{N}$$

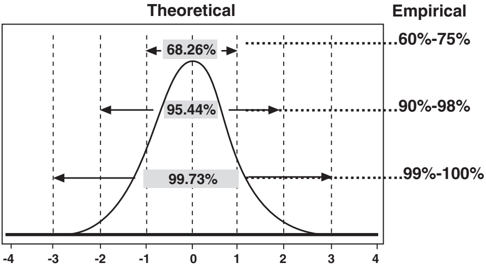
Population standard deviation

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \mu)^2}{N}}$$

Properties of a Normal Distribution

A normal distribution can be described by its mean and standard deviation. The standard normal distribution is a special case of the normal distribution and has a mean of zero and a standard deviation of one. The tails of the distribution extend to ± infinity. The area under the curve represents 100% of the possible observations. The curve is symmetrical such that each side of the mean has the same shape and contains 50% of the total area. Theoretically, about 95% of the population is contained within ± 2 standard deviations.

The Standard Normal Curve



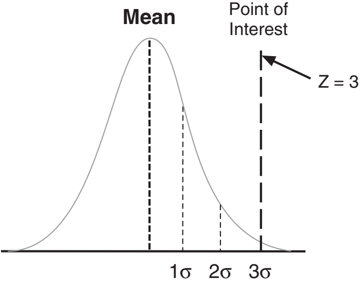
If a data set is normally distributed, then the standard deviation and mean can be used to determine the percentage (or probability) of observations within a selected range. Any normally distributed scale can be transformed to its equivalent Z scale or score using the formula:

$$Z = (x-\mu)/\sigma$$

x will often represent a lower specification limit (LSL) or upper specification limit (USL). Z, the "sigma value," is a measure of standard deviations from the mean.

Any normal data distribution can be transformed to a standard normal curve using the Z transformation. The area under the curve is used to predict the probability of an event occurring.

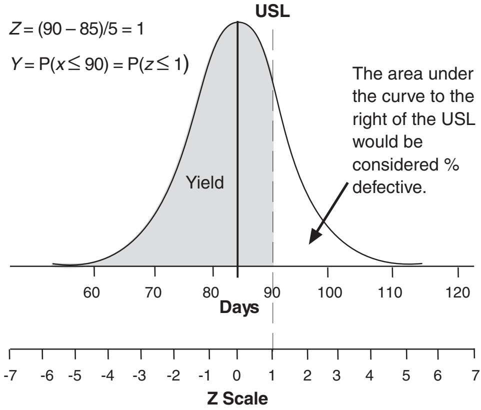
Z Transformations



Example:

If the mean is 85 days and the standard deviation is five days, what would be the yield if the USL is 90 days?

Using The Z-Transform To Predict Yield



$Z = (90 - 85)/5 = 1$

$Y = P(x \leq 90) = P(z \leq 1)$

The area under the curve to the right of the USL would be considered % defective.

$P(z < 1) = 1\text{-}P(z > 1) = 1\text{-}0.15865 = 0.8413$ Yield $\cong 84.1\%$

A standard Z table is used to determine the area under the curve. The area under the curve represents probability.

Note: A standard Z table can be found in the Appendix of this book. This particular table provides probabilities on the left side. When using other tables, verify which probability it is providing. Tables may accumulate area under the curve from the left or right tail. Graphically depicting the problem statement and practical interpretation of the results is recommended.

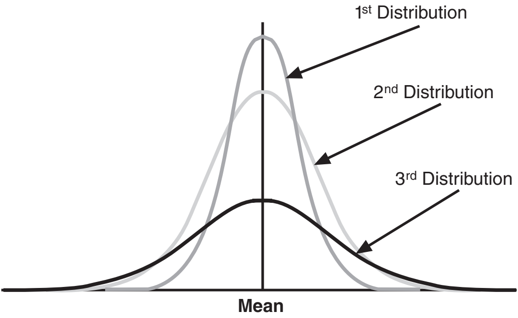
Because the curve is symmetric, the area shown as yield would be 1-P(z>1) = 0.841 or 84.1%.

In accordance with the equation, Z can be calculated for any "point of interest," x.

Variation

The following figure shows three normal distributions with the same mean. What differs between the distributions is the variation.

Three Normal Distributions



The first distribution displays less variation or dispersion about the mean. The second distribution displays more variation and would have a greater standard deviation. The third distribution displays even more variation.

Short-term vs. Long-term Variation

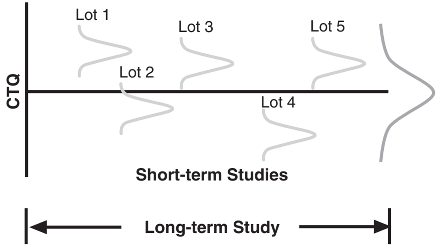
The duration over which data is collected will determine whether short-term or long-term variation has been captured within the subgroup.

There are two types of variation in every process: *common cause variation* and *special cause variation.* Common cause variation is completely random (i.e., the next data point's specific value cannot be predicted). It is the natural variation of the process. Special cause variation is the nonrandom variation in the process. It is the result of an event, an action, or a series of events or actions. The nature and causes of special cause variation are different for every process.

Short-term data is data that is collected from the process in subgroups. Each subgroup is collected over a short length of time to capture common cause variation only (i.e., data is not collected across different shifts because variation can exist from operator to operator). Thus, the subgroup consists of "like" things collected over a narrow time frame and is considered a "snapshot in time" of the process. For example, a process may use several raw material lots per shift. A representative short-term sample may consist of CTQ measurements within one lot.

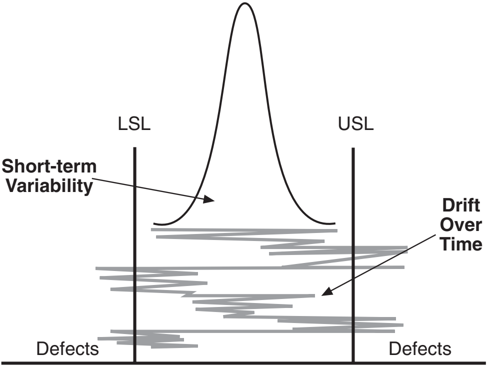
Long-term data is considered to contain both special and common causes of variation that are typically observed when all of the input variables have varied over their full range. To continue with the same example, long-term data would consist of several raw material lots measured across several short-term samples.

Process Variation Over Time



Processes tend to exhibit more variation in the long term than in the short term. Long-term variability is made up of short-term variability and process drift. The shift from short term to long term can be quantified by taking both short-term and long-term samples.

Long-term Drift



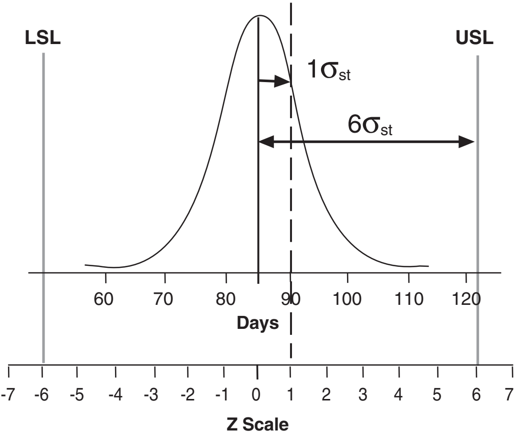
On average, short-term process means tend to shift and drift by 1.5 sigmas.

$$Z_{lt} = Z_{st} - 1.5$$

(The short-term Z (Z_{st}) is also known as the benchmark sigma value. The Rolled Throughput Yield (RTY) section of this book discusses several related Six Sigma metrics used to evaluate processes.)

A Six Sigma process would have six standard deviations between the mean and the closest specification limit for a short-term capability study. The following figure illustrates the Z-score relationship to the Six Sigma philosophy:

Z-Score Relationship To Six Sigma Philosophy

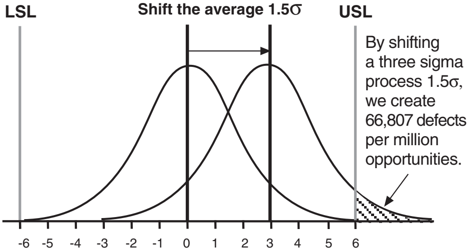


In a Six Sigma process, customer satisfaction and business objectives are robust to shifts caused by process or product variation.

Six Sigma as a Statistical Measure

Three Sigma Process

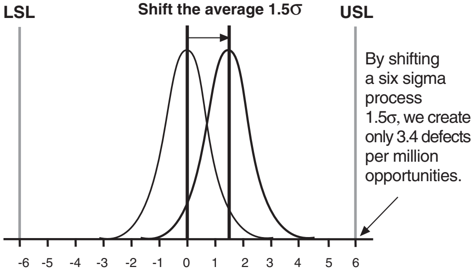
Average = 0
St. Dev. = 2
Tolerance = 12



By shifting a three sigma process 1.5σ, we create 66,807 defects per million opportunities.

Six Sigma Process

Average = 0
St. Dev. = 1
Tolerance = 12



By shifting a six sigma process 1.5σ, we create only 3.4 defects per million opportunities.

DPMO is directly related to Z. A reference chart to convert from Z_{lt} to DPMO can be found in the Appendix of this book. This chart already includes the 1.5 sigma shift. For example, shifting a Six Sigma process 1.5 sigma creates 3.4 defects per million opportunities. Recall our previous example with a $Z_{st} = 1.0$. If so, then, $Z_{lt} = 1.0 - 1.5 = -0.5$. From the conversion table, the long-term DPMO is 691,500 or 69.15% defects. The yield is (1-0.6915) = 0.3085 or 30.85%.

Process Maps

SIPOC

Why use it?

SIPOC is used to document a process at a high level and visually show the process, from suppliers' inputs to the products or services received by customers. The name comes from the column headings on a SIPOC chart: **S**uppliers, **I**nputs, **P**rocess, **O**utputs, and **C**ustomers.

What does it do?

SIPOC:

- Identifies process boundaries.
- Identifies the customers and suppliers of a process.
- Identifies the process inputs supplied by the suppliers and the process outputs used by the customer.
- Helps in identifying data collection needs.

Components of a SIPOC

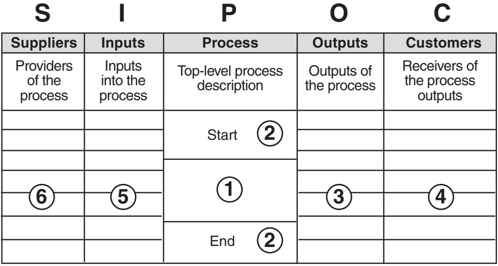
- A *process description* is an explanation of a process that provides outputs to meet the needs of customers.
- The *input and output boundaries* define the start and stop boundaries of the process.
- The *outputs* are the "results" of the process. Special care should be taken to determine how these outputs relate to the customers' expectations (CTSs) (i.e., do they meet or exceed the customer requirements?).
- The *customers* are the people who receive and put requirements on the outputs. Customers can be either internal or external; the SIPOC chart should be specific in documenting which.

- *Customer requirements and measures* are the quantifiable expectations of the process outputs. The output must be measured and then compared to customer requirements to quantify customer satisfaction.
- The *inputs* are what the process needs to function.
- The *input requirements and measures* are the quantifiable expectations the process puts on the inputs. For a process to create outputs that meet the customer requirements, it must have inputs that meet specific requirements. The SIPOC should document what the process requires of the inputs that are received before the start of the process.
- The *suppliers* provide the necessary inputs to the process. The SIPOC should be as specific as possible in documenting supplier information. For example, if a supplier is internal, the SIPOC should list the function and point of contact for the particular process input.

How do I do it?

The following figure shows the steps in creating a SIPOC. The numbers in the graphic correspond to the numbers of the steps that follow.

Creating a SIPOC



S	I	P	O	C
Suppliers	**Inputs**	**Process**	**Outputs**	**Customers**
Providers of the process	Inputs into the process	Top-level process description	Outputs of the process	Receivers of the process outputs
		Start ②		
⑥	⑤	①	③	④
		End ②		

1. **Provide a description of the process.**
2. **Define the start and end of the process that the project is focused on.**
3. **List the outputs of the process.**
    - Requirements of the outputs should also be listed, as well as how requirements will be measured.
4. **List the customers of each process output.**
5. **List the inputs required for the process, as well as how these inputs will be measured.**
    - The quantifiable expectations of the process should also be listed.
6. **List the suppliers of the process.**

A SIPOC for a Lecture Development Process

S	I	P	O	C
Suppliers	**Inputs**	**Process**	**Outputs**	**Customers**
Subject expert	Class objectives	Start: Need for lecture development identified	Class outline	Department head
Department head	Class subject			
University	Teaching guidelines	Develop class lecture	Lecture developed in two weeks	Department head, teacher
Department head	Subject expert			
Department head	Target time per lecture (50+/-5 min.)		Reviews	Subject expert
Department head	Reviewers	End: Lecture materials printed	Printed materials	Lecturer
Printing company	Printing service			

Process Mapping

Why use it?

Process mapping identifies the flow of events in a process as well as the inputs (x's) and outputs (y's) in each step of a process.

What does it do?

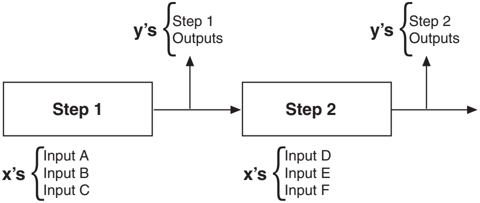
Process mapping:

- Graphically identifies the steps in a process.
- Visually shows the complexity of a process and identifies sources of non-value-added activities (i.e., rework loops and redundancy in a process).
- Identifies the key process input variables (x's) that go into a process step and the resultant key output variables (y's).
- Classifies all input variables (x's) to a process step as noise, controllable factors, or standard operating procedures (SOP).
- Builds on the Flowchart tool by adding more process information.

Components of a Process Map

- The *inputs* (x's) are the key process variables that are required to perform a process step. Inputs could be anything in the categories of people, methods, materials, machinery, measurements, or environment.
- The *process steps* are the tasks that transform the inputs of the process into the outputs of the process.
- The *outputs* (y's) are the key variables resulting from the performance of the process step. Outputs can be goods, services, measurements, or consequences.

A Process Map

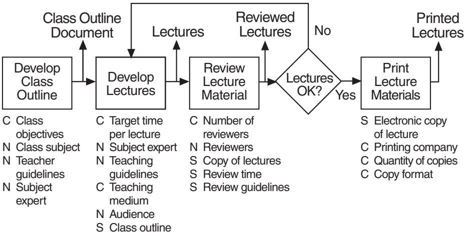


How do I do it?

1. **Define the scope of the process.**
    - Clearly define where the process starts and stops. These are the process boundaries.
    - Process maps can be done at different levels such as an overall level, operation level, or micro-task level. The team should decide which level is appropriate.
    - The process scope can be defined with a SIPOC.
2. **Document all the steps in the process.**
    - To do this correctly, "walk through" the process by pretending to be the product or service being operated on. Document all the steps of the as-is process, not the should-be process. Activities are shown as a rectangle on a process map.
    - Document the decision points. Decision points must pose a question. The response to the question will lead to multiple paths. Decision points are shown as a diamond on a process map.
3. **List all outputs (y's) at each process step.**
4. **List all inputs (x's) at each process step.**

5. **Classify all inputs (x's) as:**
   - Controllable (C): Inputs that can be changed to see the effect on the output (y). Examples are speed or feed rate on a machine, temperature or pressure in a thermodynamic process, or document type or batch size in a transactional process.
   - Standard operating procedures (S): Standard methods or procedures for running the process. Examples are cleaning, safety, and loading of components in an industrial process, and training, calling method, or data entry items in a transactional process.
   - Noise (N): Things that cannot or that have been chosen not to be controlled due to cost or difficulty. Examples are ambient temperature or humidity in an industrial process, or computer network or operator in a transactional process.
6. **As applicable, list the operating specification and process targets for controllable inputs.**
   - For the controllable inputs that have these targets, list the target input and the specified lower and/or upper limits on the setting.

Class Lecture Development Process Map



Controllable Input Variable	Target	Lower Spec.	Upper Spec.
Target Time	50	45	60

Key
C - Controllable
S - SOP
N - Noise

Rolled Throughput Yield

Why use it?

Rolled Throughput Yield (RTY) is used to assess the true yield of a process that includes a hidden factory. A hidden factory adds no value to the customer and involves fixing things that weren't done right the first time.

What does it do?

RTY determines the probability of a product or service making it through a multistep process without being scrapped or ever reworked.

How do I do it?

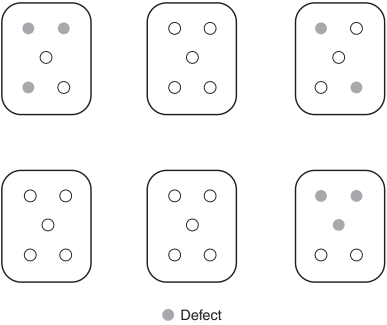
There are two methods to measure RTY:

Method 1 assesses defects per unit (dpu), when all that is known is the final number of units produced and the number of defects.

- A *defect* is defined as something that does not conform to a known and accepted customer standard.
- A *unit* is the product, information, or service used or purchased by a customer.
- An *opportunity for a defect* is a measured characteristic on a unit that needs to conform to a customer standard (e.g., the ohms of an electrical resistor, the diameter of a pen, the time it takes to deliver a package, or the address field on a form).
- *Defective* is when the entire unit is deemed unacceptable because of the nonconformance of any one of the opportunities for a defect.

Shown in the following diagram are six units, each containing five opportunities for a defect.

Opportunities for a Defect



Given that any one defect can cause a unit to be defective, it appears the yield of this process is 50%. This, however, is not the whole story. Assuming that defects are randomly distributed, the special form of the Poisson distribution formula

$$\mathrm{RTY} = e^{-dpu}$$

can be used to estimate the number of units with zero defects (i.e., the RTY).

The previous *figure* showed eight defects over six units, resulting in 1.33 dpu. Entering this into our formula:

$$\mathrm{RTY} = e^{-1.33}$$

$$\mathrm{RTY} = 0.264$$

According to this calculation, this process can expect an average of 26.4% defect-free units that have not been reworked (which is much different than the assumed 50%).

Method 2 determines throughput yield (Y_{tp}), when the specific yields at each opportunity for a defect are known.

If, on a unit, the yield at each opportunity for a defect is known (i.e., the five yields at each opportunity in the previous figure), then these yields can be multiplied together to determine the RTY. The yields at each opportunity for a defect are known as the throughput yields, which can be calculated as

$$Y_{tp} = e^{-dpu}$$

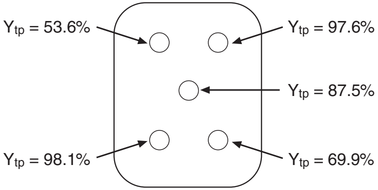
for that specific opportunity for a defect for attribute data, and

$$Y_{tp} = 1 - P(\text{defect})$$

for variable data, where P(defect) is the probability of a defect based on the normal distribution.

Shown in the following figure is one unit from the previous figure in which the associated Y_{tp}'s at each opportunity were measured for many units.

Throughput Yield
at Each Opportunity for a Defect



Multiplying these yields together results in the RTY:

$$RTY = Y_{tp1} \times Y_{tp2} \times Y_{tp3} \times Y_{tp4} \times Y_{tp5}$$

$$RTY = 0.536 \times 0.976 \times 0.875 \times 0.981 \times 0.699$$

$$RTY = 0.314$$

According to this calculation, an average of 31.4% defect-free units that have not been reworked can be expected.

Defects Per Million Opportunities

Why use it?

Defects per million opportunities (DPMO) helps to determine the capability of a process.

What does it do?

DPMO allows for the calculation of capability at one or more opportunities and ultimately, if desired, for the entire organization.

How do I do it?

Calculating DPMO depends on whether the data is variable or attribute, and if there is one or more than one opportunity for a defect.

If there is:

- *One opportunity with variable data*, use the Z transform to determine the probability of observing a defect, then multiply by 1 million.
- *One opportunity with attribute data*, calculate the percent defects, then multiple by 1 million.
- *More than one opportunity with both variable and/or attribute data*, use one of two methods to determine DPMO.

1. **Calculate the total defects per opportunity (DPO).**
   - To calculate DPO, sum the defects and sum the total opportunities for a defect, then divide the defects by the total opportunities and multiply by 1 million.

     Example:

     If there are eight defects and thirty total opportunities for a defect, then

     $$\text{DPMO} = (8/30) \times 1{,}000{,}000 = 266{,}667$$

   - When using this method to evaluate multiple opportunity variable data, convert the calculated DPMO into defects and opportunities for each variable, then sum them to get total defects and opportunities.

     Example:

     If one step in a process has a DPMO of 50,000 and another step has a DPMO of 100,000, there are 150,000 total defects for 2 million opportunities or 75,000 DPMO overall.

2. **Calculate the average yield per opportunity, also known as the normalized yield (Y_{na}).**
   - To calculate Y_{na} from RTY, assuming there are m opportunities per unit, take RTY to the 1/m power.

     $$Y_{na} = \text{RTY}^{(1/m)}$$

     To calculate RTY from Y_{na}, take Y_{na} to the mth power.

     $$\text{RTY} = Y_{na}^{m}$$

     $$\text{DPMO} = (1-Y_{na}) \times 1{,}000{,}000$$

Example:

If there are five opportunities per unit and the RTY is 0.264, then:

$$Y_{na} = 0.264^{(1/5)}$$

$$Y_{na} = 0.766$$

$$DPMO = (1- 0.766) \times 1{,}000{,}000 = 234{,}000$$

The difference between DPO and Y_{na} is that Y_{na} is an estimate based on the Poisson distribution, and DPO is an actual calculation. As the defect rate falls below 10%, these values converge.

Sigma Values

Why use it?

Sigma values are calculated to determine a baseline for an opportunity, process, or product. Sigma values can also be used to fairly compare different products, services, information, or divisions within a organization and, if desired, benchmark the like.

Note: Sigma has many different definitions and can be used in many different ways:

- As a benchmark.
- As a population's standard deviation.
- As a baseline measure that describes how far a process mean is from the nearest specification.
- As a measure of distance (e.g., two process means are 4.5 sigma apart).

What does it do?

Sigma helps establish baselines and set targets, goals, and objectives against which progress can be measured.

How do I do it?

Once DPMO has been calculated, sigma values can be looked up in a table. Tables may be found in many common computer software packages and in appendices of statistical books. Remember that it is necessary to understand whether the data collected is short term or long term, as it may be necessary to either add or subtract 1.5 to the lookup value.

Partial DPMO to Z Table

DPMO	Z	DPMO	Z	DPMO	Z	DPMO	Z	DPMO	Z
500000	0.000	95000	1.311	2500	2.807	480	3.302	75	3.791
480000	0.050	90000	1.341	2400	2.820	460	3.314	70	3.808
460000	0.100	85000	1.372	2300	2.834	440	3.326	65	3.826
440000	0.151	80000	1.405	2200	2.848	420	3.339	60	3.846
420000	0.202	75000	1.440	2100	2.863	400	3.353	55	3.867
400000	0.253	70000	1.476	2000	2.878	380	3.367	50	3.891
380000	0.305	65000	1.514	1900	2.894	360	3.382	45	3.916
360000	0.358	60000	1.555	1800	2.911	340	3.398	40	3.944
340000	0.412	55000	1.598	1700	2.929	320	3.414	35	3.976
320000	0.468	50000	1.645	1600	2.948	300	3.432	30	4.013
300000	0.524	45000	1.695	1500	2.968	280	3.450	25	4.056
280000	0.583	40000	1.751	1400	2.989	260	3.470	20	4.107
260000	0.643	35000	1.812	1300	3.011	240	3.492	15	4.173
240000	0.706	30000	1.881	1200	3.036	220	3.515	10	4.265
220000	0.772	25000	1.960	1100	3.062	200	3.540	5	4.417
200000	0.842	20000	2.054	1000	3.090	180	3.568	4	4.465
180000	0.915	15000	2.170	900	3.121	160	3.599	3	4.526
160000	0.994	10000	2.326	800	3.156	140	3.633	2	4.611
140000	1.080	5000	2.576	700	3.195	120	3.673	1	4.753
120000	1.175	4000	2.652	600	3.239	100	3.719	0.5	4.892
100000	1.282	3000	2.748	500	3.291	80	3.775	0.1	5.199

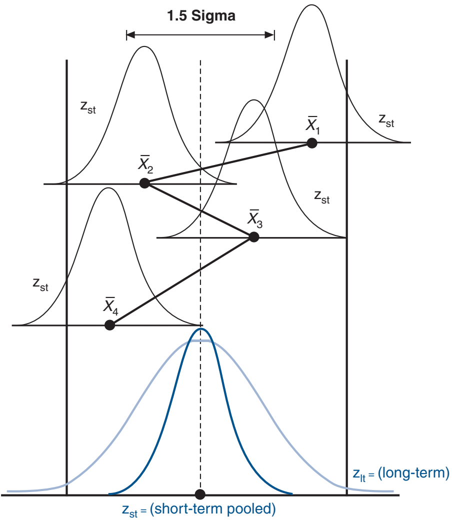
Not Shifted: Long-term DPMO will give long-term Z.

Short-term data is considered free of special causes. For example, data collected over one shift does not allow any special causes due to differences in shift. In a transactional process, short-term data could measure one administrator over one day.

Long-term data is considered to contain both special and random cause variation, typically observed when the input variables have varied over their full range.

Processes tend to exhibit more variation in the long term than the short term. Shown below is a process in which subgroups of data were collected on a daily basis (small bell curves) for an extended period of time. The shifting and drifting of the subgroup averages (the shift factor) is due to many factors such as tool wear, different operators working the process, different lots of raw materials, etc. It has been demonstrated that because of these many causes, the subgroup means tend to shift and drift, on average, 1.5 standard deviations.

Subgroup Drift



How do I practically use the shift factor?

If short-term data has been collected, then the calculation will be to baseline a process to determine a short-term sigma (Z_{st}). If long-term data is not available but long-term performance needs to be estimated, then 1.5 can be subtracted from the Z_{st} to estimate long-term performance. (The opposite also is true: to estimate short-term performance, add 1.5 to the Z_{lt}.)

Using the Shift Factor

			To know:	
			Z_{st}	Z_{lt}
			Short-term capability	Long-term capability
With data collected:	Z_{st}	Short-term data	✔	**Subtract 1.5**
	Z_{lt}	Long-term data	**Add 1.5**	✔

$$Z_{lt} = Z_{st} - 1.5$$

Note: Use 1.5 as the shift factor until enough data on the process has been collected to distinguish between long-term and short-term variation. Once enough data has been collected, the exact shift factor for the process can then be determined, although it is difficult and data intensive to do so when using attribute data.

Example:

A DPMO of 266,667 was calculated in the previous chapter. If we consider it to be long-term data, looking up the sigma value in a table shows a long-term sigma value of 0.62. Considering the need to report a short-term sigma value, we can add 1.5 to the sigma value to obtain a short-term sigma value of 2.12.

Cause & Effect/ Fishbone Diagram

Why use it?

Cause & Effect (C&E) Diagrams allow a team to identify, explore, and graphically display, in increasing detail, important possible causes related to a problem or condition to discover its root cause(s).

What does it do?

A C&E Diagram:

- Enables a team to focus on the content of the problem, not on the history of the problem or differing personal interests of team members.
- Creates a snapshot of the collective knowledge and consensus of a team around a problem. This builds support for the resulting solutions.
- Focuses the team on causes, not symptoms.

How do I do it?

1. **Select the most appropriate Cause & Effect format.**

   There are two major formats:

   - A *dispersion analysis type* is constructed by placing individual causes within each "major" cause category and then asking of each individual cause "Why does this cause (dispersion) happen?" This question is repeated for the next level of detail until the team runs out of causes. (The graphic examples shown in step 3 of this section are based on this format.)

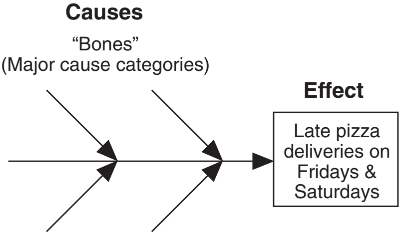
- A *process classification type* uses the major steps of the process in place of the major cause categories. The root cause questioning process is the same as the dispersion analysis type.

2. **Generate the causes needed to build a Cause & Effect Diagram, using either:**
   - Brainstorming without previous preparation.
   - Check Sheets based on data collected by team members before the meeting.

3. **Construct the Cause & Effect/Fishbone Diagram.**

   a) Place the problem statement in a box on the righthand side of the writing surface.

   - Allow plenty of space. Use a flipchart sheet, butcher paper, or a large white board. A paper surface is preferred because the final Cause & Effect Diagram can be moved.



Tip Make sure everyone agrees on the problem statement. Include as much information as possible on the "what," "where," "when," and "how much" of the problem. Use data to specify the problem.

b) Draw major cause categories or steps in the production or service process. Connect them to the "backbone" of the fishbone chart.

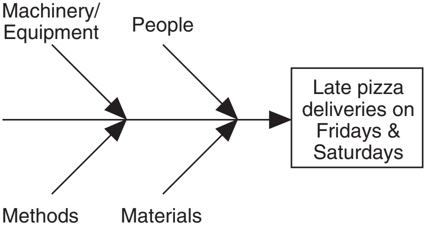
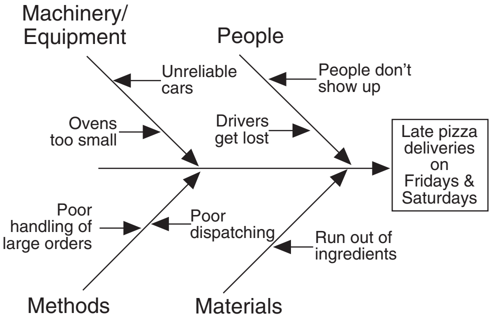


Illustration Note: In a process classification type format, replace the major "bone" categories with: "Order Taking," "Preparation," "Cooking," and "Delivery."

- Be flexible in the major cause "bones" that are used. For a *Production Process* the traditional categories are: Machines (equipment), Methods (how work is done), Materials (components or raw materials), and People (the human element). For a *Service Process* the traditional methods are: Policies (higher-level decision rules), Procedures (steps in a task), Plant (equipment and space), and People. In both types of processes, Environment (buildings, logistics, humidity, temperature, and space), and Measurement (calibration and data collection) are also frequently used. *There is no perfect set or number of categories. Make them fit the problem.*



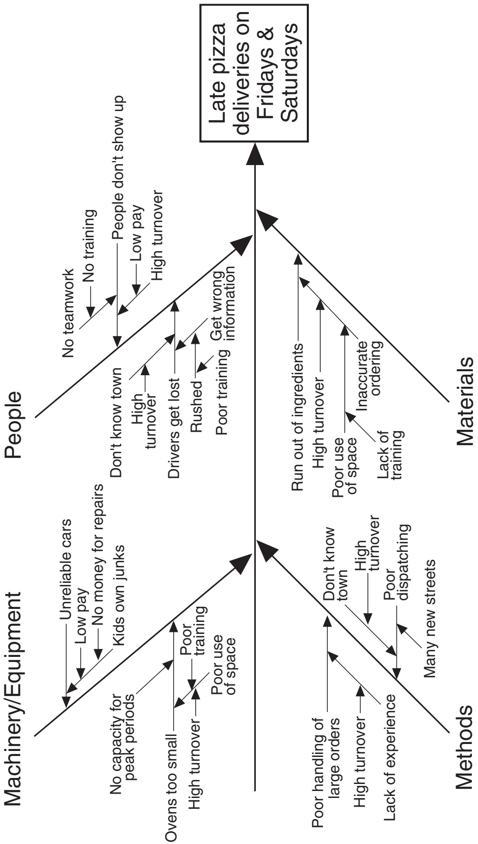
c) Place the brainstormed or data-based causes in the appropriate category.

- In brainstorming, possible causes can be placed in a major cause category as each is generated, or only after the entire list has been created. Either works well but brainstorming the whole list first maintains the creative flow of ideas without being constrained by the major cause categories or where the ideas fit in each "bone."
- Some causes seem to fit in more than one category. Ideally each cause should be in only one category, but some of the "people" causes may legitimately belong in two places. Place them in both categories and see how they work out in the end.

Tip If ideas are slow in coming, use the major cause categories as catalysts (e.g., "What in 'materials' is causing . . . ?").

d) Ask repeatedly of each cause listed on the "bones," either:

- "Why does it happen?" For example, under "Run out of ingredients," this question would lead to more basic causes such as “Inaccurate ordering,” “Poor use of space,” and so on.



- "What could happen?" For example, under "Run out of ingredients," this question would lead to a deeper understanding of the problem such as "Boxes," "Prepared dough," "Toppings," and so on.

Tip For each deeper cause, continue to push for deeper understanding, but know when to stop. A rule of thumb is to stop questioning when a cause is controlled by more than one level of management removed from the group. Otherwise, the process could become an exercise in frustration. Use common sense.

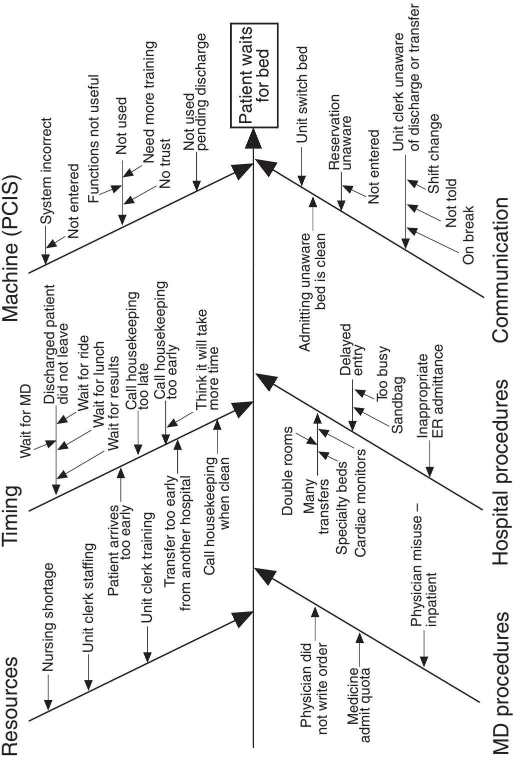
e) Interpret or test for root cause(s) by one or more of the following:

- Look for causes that appear repeatedly within or across major cause categories.
- Select through either an unstructured consensus process or one that is structured, such as Nominal Group Technique or Multivoting.
- Gather data through Check Sheets or other formats to determine the relative frequencies of the different causes.

Variations

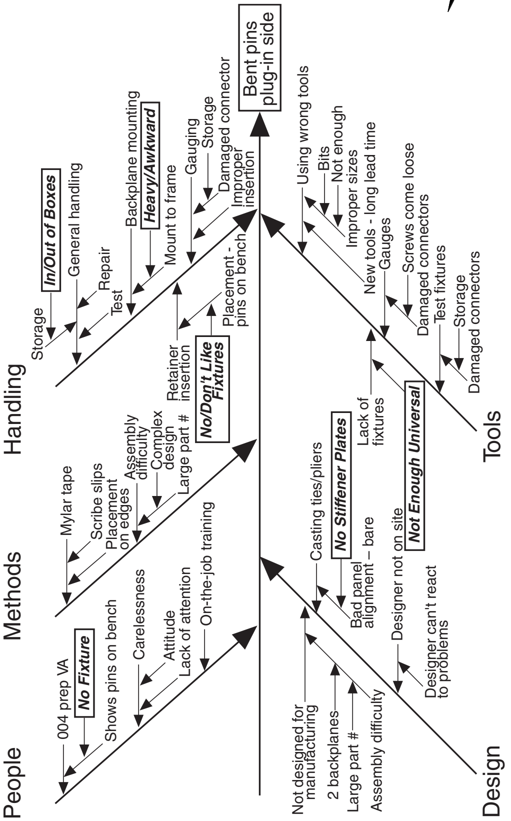
Traditionally, Cause & Effect Diagrams have been created in a meeting setting. The completed "fishbone" is often reviewed by others and/or confirmed with data collection. An effective alternative is to prominently display a large, highly visible, blank fishbone chart in a work area. Everyone posts both potential causes and solutions on Post-it™ Notes in each of the categories. Causes and solutions are reviewed, tested, and posted. This technique opens up the process to the knowledge and creativity of every person in the operation.

Bed Assignment Delay



Information provided courtesy of Rush-Presbyterian-St. Luke's Medical Center

Causes for Bent Pins (Plug-In Side)



Information provided courtesy of AT&T

Measurement Systems Analysis

Why use it?

Measurement systems, if not functioning properly, can be a source of variability that can negatively impact capability. If measurement is a source of variability, organizations can be rejecting good units and/or accepting bad units. Therefore, it must be determined if the measurement system is reliable before the baseline capability can be determined. Doing so allows the organization to properly accept good units and properly reject bad units, thus establishing the true quality level.

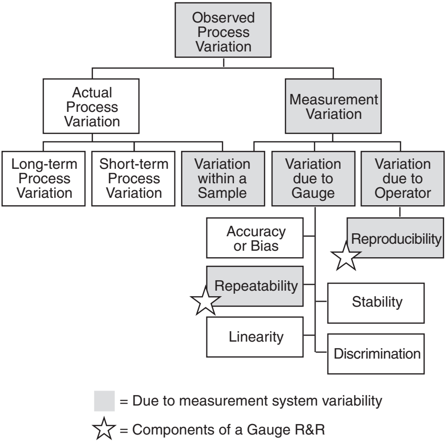
What does it do?

Measurement systems analysis (MSA) is a series of designed tests that allows an organization to determine whether their measurement system is reliable. There are two types of MSAs; the choice of which one to use depends on whether the data is variable or attribute.

Variable Data

For variable data, the measurement system is comprised of the units being measured, the gauge, and the operators and their methods. The tree diagram on the next page shows the relationship of the sources of variation.

Sources of Variation



When conducting an MSA, the organization must evaluate the bias, linearity, stability, discrimination, and variability (or precision) in the measurement system.

The *bias* is the difference between the observed average value of measurements and a known standard or master value. If bias exists in the average measured value, the measurement system may require calibration.

The *linearity* determines whether a bias exists in the measurement system over its operating range. For example, thermometers or scales may be biased when measuring at the low end of the scale, if the instruments are intended for larger values of measure.

The *stability* determines the measurement system's ability to measure consistently over time such that the measurement system does not drift.

The *discrimination* or resolution of the measurement system is the ability to detect small changes in the characteristic being measured.

Variability or Precision:

- The *repeatability* is the ability of the measurement system to return the same measured value when one operator takes repeated measurements of the same unit.
- The *reproducibility* is the degree of agreement when multiple operators measure the same characteristic on the same unit.

Attribute Data

For attribute data, the measurement system is comprised of the units being measured, the gauge, and the operators and their methods. In this MSA, the operators are frequently the gauge and the evaluation consists of how well they can look at a characteristic to either determine its acceptability (yes/no) or properly rate it on a scale. Examples include operators inspecting rolls of cloth for defects, or an operator's ability to complete a purchase order form properly. This type of MSA can determine whether:

1. An operator can repeat his or her measures when evaluating many units multiple times (*within operator* variation).
2. An operator cannot only repeat his or her own measures on multiple units, but can match those measures to known standards for the units (accuracy).

3. Multiple operators can match the measurements of one another on multiple units (*between operator* variation).
4. Multiple operators not only match the measurements of one another on multiple units, but can all match the known standard for these units.

How do I do it?

MSA for Variable Data

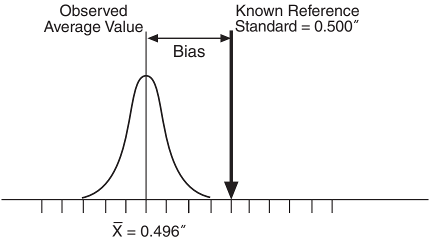
A. Bias - To determine whether bias exists in the system:

1. **Obtain a known standard that represents a value within the normal range of the characteristic of interest.**
2. **Have one operator with one gauge measure the known standard a minimum of ten times, record these values, and calculate the average.**
3. **Compare the average to the known standard.**
   - If the average is less than the known standard, then offset the gauge positively by this amount.
   - If the average is greater than the known standard, then offset the gauge negatively by this amount.

Example:

A known standard was obtained and certified to be 0.500". One operator using one gauge measured this standard ten times and determined the average value to be 0.496". Because the average value is 0.004" less than the standard, the gauge must be positively offset by 0.004".

Bias



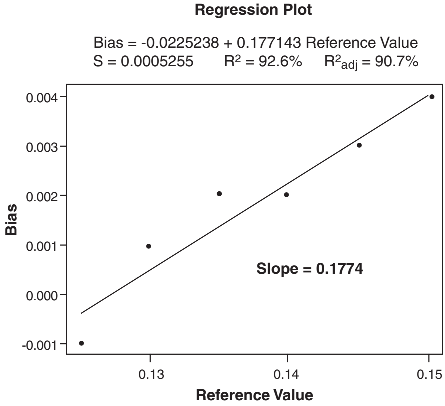
B. Linearity - To determine whether bias exists over the operating range of the gauge:

1. **Identify four or more standard/reference units that span the likely range over which the measurement system is to be used.**
2. **Identify one operator to determine the bias of the gauge over the operating range of the process variation.**
3. **Create a scatter plot with the standard/reference units on the x axis and the bias values on the y axis.**
4. **Create a regression equation for this data and determine whether the goodness of fit term (R^2) is acceptable.**
    - The slope of the regression line determines the linearity. Generally, the lower the absolute value of the slope, the better the linearity; the converse is also true (the higher the absolute value of the slope, the worse the linearity).

Example:

A linearity study was conducted in which six samples that spanned the operating range of the gauge were identified and certified. (Certified is when a unit is measured with a known high precision instrument.) One operator measured each of the six samples ten times and the bias for the six units was calculated. The data was graphed using a fitted line plot and the fit was assessed using R^2.

Linearity



If the system is determined to be nonlinear, check for a defective gauge, wrong standard/reference values, incorrect operator methods of measuring, or an improperly calibrated gauge.

C. Stability - To determine whether the measurement system's bias is drifting over time:

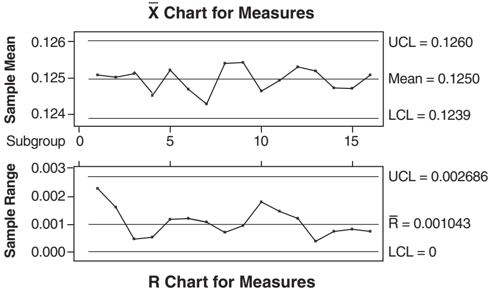
1. **Obtain a standard/reference unit that falls in the mid-range of the production values.**
2. **On a regular basis (weekly or monthly), measure the standard/reference value three to five times.**

3. **Plot this data in X-bar ($\bar{X}$) and R control charts.**
4. **Monitor these charts regularly to determine whether the gauge needs to be calibrated.**
5. **If desired, create the same control charts for reference values on the low and high side of production.**

Example:

A standard/reference value is measured three times on a weekly basis . The data is plotted in an $\bar{X}$ and R control chart.

Stability



$\bar{X}$ Chart for Measures

R Chart for Measures

Both charts are used to determine the stability or repeatability of the measurements over time. The R chart captures the *within subgroup* (multiple readings of the same part) variation over time. The R chart generates the control limits for the $\bar{X}$ chart. Captured *between subgroups* (as shown in the $\bar{X}$ chart) are the week-to-week average measures of the test part. Because the $\bar{X}$ chart is in control, the measurement system is exhibiting good stability over time. If there was an issue with stability, a design of experiments could be applied to determine the contributors to the poor stability.

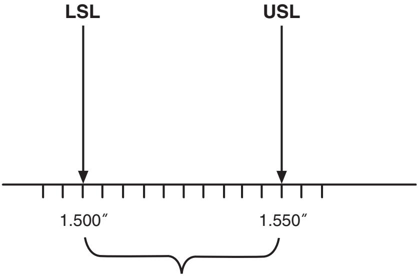
Discrimination

Discrimination is the ability of the measurement system to detect small changes in the characteristic of interest. As a general rule, the measurement system should be able to discriminate to one-tenth the tolerance (USL - LSL).

Example:

If a critical characteristic of a part is its length, and the lower and upper specification limits are 1.500" and 1.550", respectively, the measurement system should be able to measure to one-tenth the tolerance or (1.550" - 1.500")/10 = 0.005". Therefore, at a minimum, any gauge used needs to measure to 0.005".

Discrimination



The measurement system must be able to resolve the tolerance to ten equal divisions of 0.005″.

Consider instead in this example, if the measurement system could only measure to 0.050". In this case, these parts could only be classified as meeting the upper or lower specification limit and nothing in between. Therefore, this gauge would not provide adequate discrimination to properly accept or reject parts.

MSA Components of Variation

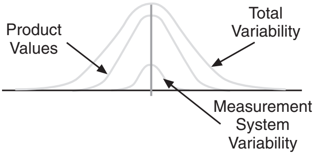
Any measurement of a part not only measures the true part value, but also measures any variability that may exist because of the poor repeatability of the gauge and/or the poor reproducibility of the operators and their methods of measuring. Obviously, it is desirable to ascertain the true part value free of any other source of variability to determine the true capability of the process. A test known as a Gauge Repeatability & Reproducibility (GR&R) test is conducted to determine whether excessive variability exists in the measurement system. This test is designed such that the sources of variability within the measurement system, which include the total variability (TV), the product variability, and the measurement system variability (also known as measurement system error or precision, P), can be partitioned as shown in the following figure:

MSA Components of Variation

$$\hat{\sigma}^2\ \textit{Total} \;=\; \hat{\sigma}^2\ \textit{product} \;+\; \hat{\sigma}^2\ \textit{ms}$$

Total variability = product variability + measurement system variability

$$\hat{\sigma}^2\ \text{repeatability} \;+\; \hat{\sigma}^2\ \text{reproducibility}$$



As shown in the figure, measurement system variability can further be partitioned into:

- Measurement system repeatability: The ability of one operator using one gauge to measure one part multiple times with minimal variability.
- Measurement system reproducibility: The ability of multiple operators to produce similar average measures for multiple parts, with minimal variability in the average measured values.

Once all of these variances have been calculated, the organization can determine whether the measurement system is reliable based on the following calculations. If the measurement system is deemed unreliable, these variances can help determine whether the problem is repeatability and/or reproducibility.

GR&R Acceptance Criteria

	% Contribution	% P/TV	% P/T
	$\frac{\hat{\sigma}^2\ ms}{\hat{\sigma}^2\ Total} \times 100$	$\frac{\hat{\sigma}\ ms}{\hat{\sigma}\ Total} \times 100$	$\frac{5.15 \times \hat{\sigma} ms}{Tolerance} \times 100$
Marginally Acceptable	<9%	<30%	<30%
Good	<4%	<20%	<20%
Excellent	<1%	<10%	<10%

- *Percent Contribution* is the preferred Six Sigma metric. It is similar to the P/TV ratio described below, but it is a ratio of variances. Recall from basic statistics that variances add; the Percent Contribution for each source of variation will sum to 100%, making it easier to identify the greatest source of variation.
- *Precision to Total Variation* (P/TV) is the ratio of the measurement system standard deviation to the total

observed standard deviation. This metric is used to determine if the organization can measure its process variation well enough to validate its process improvements through hypothesis testing.

The total variation can be estimated in two ways: 1) It may be estimated using a historical standard deviation of the process. 2) If the samples from the study represent the process distribution, the standard deviation of the study may be used as an estimate of the process.

- *Precision to Tolerance* (P/T) is the ratio of 5.15 times the measurement system standard deviation, to the tolerance (USL - LSL). This metric is used to determine if the organization can appropriately accept or reject product. (The value "5.15" is the number of standard deviations needed to capture 99% of the variation.) The P/T ratio is often a requirement of the quality system, especially in the automotive industry. Caution should be taken to ensure that the tolerancing on the product is realistic. Inflated tolerances can make a measurement system "look" better than it actually is.

How do I do a Continuous GR&R test?

1. **Identify the characteristic on the unit to be measured, the gauge, and the operators who use the gauge.**

2. **Identify a number of units (typically ten units) that span the range of the long-term process variability.**

   - This may require samples to be collected over several days or weeks.

3. **Conduct the GR&R in the environment where the measurement takes place.**

4. **Estimate repeatability and reproducibility by conducting a test using three operators and ten**

units. The units need to be measured at least twice by each operator.

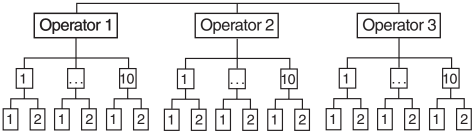
- This test should be randomized; therefore, have the first operator measure the ten units in random order, then have the second operator measure the ten units in random order, and then the third operator. After the operators have measured all of the units once, they are to measure the units again in random order to obtain the repeat measures. There should be a total of sixty measures in this designed test (3 x 10 x 2).

5. **Calculate the variances using the ANOVA method.**
   - Many software packages can be used to calculate variances using the ANOVA method.
6. **Interpret the results graphically and analytically to determine whether the measurement system is acceptable, needs repair, or must be replaced.**

Example:

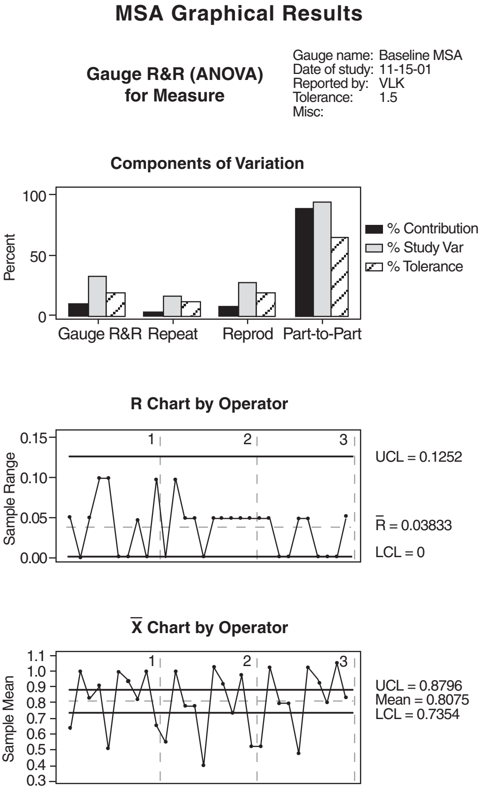
A Black Belt needed to determine the baseline capability of the filament diameter of a light bulb. However, prior to determining capability, the Black Belt knew she had to conduct an MSA. She selected ten filaments, the gauge used to measure these filaments, and three operators to use this gauge. She then created the following sampling plan:

MSA Sampling Plan



- Three operators, ten parts, two trial measures
- Each operator measures the same ten parts, twice in random order.

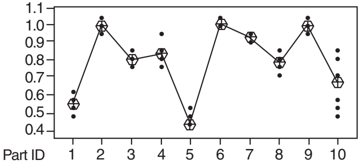
The following figure shows what the graphical output of this MSA would look like.

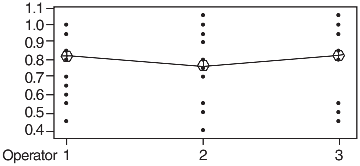


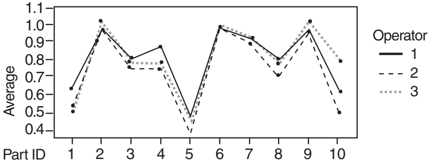
Gauge name: Baseline MSA
Date of study: 11-15-01
Reported by: VLK
Tolerance: 1.5
Misc:

Continued on next page

MSA Graphical Results, continued


By Part ID


By Operator


Operator-by-Part ID Interaction

Interpreting the graphical results:

When interpreting the results, it is important to always assess the range chart (R chart) for stability first. Assessing the range chart for stability ensures that there are no special causes. (Special causes should be corrected and the MSA repeated.) Special causes in the range chart will increase the average range and in turn will inflate the distance between the control limits in the average chart. In the filament example above, the range chart is in control; therefore, the system is stable.

Secondly, it is important to assess discrimination from the range chart. A recommended guideline is to ensure that at least five levels of possible values in the range chart, including zero, are evident. A lack of discrimination may also be the result of rounding-off values. There are only three levels of values, including zero, in our example. This is an immediate flag that discrimination of the gauge being used to measure the filaments may be an issue, unless the inspectors are rounding the measures.

Captured in the range chart are measures within part. This variation is reflected between the control limits on the average ($\overline{X}$) chart. Captured in the average chart is the part-to-part variation between operators. In our example, fifty to seventy percent of the averages are outside of the control limits on the average chart, indicating that the variation *within subgroup* (measurement within part) is less than the variation *between subgroup* (part-to-part). Ideally, we want to be able to detect part-to-part variation, so out-of-control points on the average chart are desired in this case. Measurement variation should be much less than part-to-part variation, as indicated in this example.

Software packages offer charts other than just the $\overline{X}$ and R charts. The components of variation bar chart in this MINITAB™ software output indicates that the largest source of variation is part-to-part. Repeatability is small compared to reproducibility. The total Gauge R&R (% contribution) is the sum of the variance components of reproducibility and repeatability compared to the total study variance.

Reproducibility is evidenced in the average chart between operators 1, 2, and 3. The "By Operator" chart is an overlay of the patterns in the average chart for each operator. Because the operators measured the same parts, the same results or patterns from part-to-part would be expected between operators.

Because the sampling plan is "crossed" (see the Multi-Vari charts chapter in this book for more information on crossed designs) between operator and part, there is a potential for an operator-by-part interaction. This is indicated by the crossing lines in the "Operator-by-Part ID Interaction" chart, which shows that not all operators measure the same parts the same way.

Interpreting the analytical results:

The following figure shows the MSA analytical results for the filament example previously cited.

MSA Analytical Results

Source	StdDev (SD)	Study Var (5.15 x SD)	% Study Var (%SV)	% Tolerance (SV/T)	% Contribution (of VarComp)
Total Gauge R&R	0.066615	0.34306	32.66	22.87	10.67
Repeatability	0.035940	0.18509	17.62	12.34	3.10
Reproducibility	0.056088	0.28885	27.50	19.26	7.56
Operator	0.030200	0.15553	14.81	10.37	2.19
Operator-by-Part ID	0.047263	0.24340	23.17	16.23	5.37
Part-To-Part	0.192781	0.99282	94.52	66.19	89.33
Total Variation	0.203965	1.05042	100.00	70.03	100.00

According to these results, the measurement system is unacceptable because the measurement system variation (total GR&R) of 10.67% is too high. Values less than 9% are acceptable and less than 1% is considered excellent. (See the GR&R Acceptance Criteria table earlier in this chapter.)

It appears the majority of the variation in the measurement system (10.67%) is due to reproducibility (7.56%). Therefore, the organization's goal is to determine why the measurements are not reproducible. Reproducibility is broken down into its components of operator and operator-by-part interaction. The interaction accounts for 5.37% of the total process variation. The question the organization would have to answer to solve this problem is why some operators measure some parts differently than others.

Destructive Testing

In many instances, the characteristic being measured (i.e., strength or moisture) is destroyed during the measurement, so a second or third operator cannot measure the same part.

Typically, a GR&R uses *ten* parts, three operators, and two measures per part for a total of sixty measures. To conduct the GR&R where the parts are destroyed, ten batches with six parts per batch are needed, for a total of *sixty* parts that are measured. The batches must be produced such that they represent the long-term variability of the process and the parts contained within a batch are assumed to be consistent.

Each operator will measure two parts per batch and the results will be analyzed. This destructive GR&R uses a nested ANOVA to analyze the data vs. a crossed ANOVA in the nondestructive test. (Nested refers to parts being unique to the operator.)

MSA for Attribute Data

When the characteristic to be measured is attribute in nature (e.g., the correct name in a field on a form, the correct color blue, or a rank on a scale by an operator), then the organization would need to conduct an

Attribute Gauge Repeatability & Reproducibility study. Depending on the test, the objective of the study would be to ensure operators can either discern between good and bad or rank a characteristic on a scale and get the correct answer. In this test, the operator is frequently the gauge.

How do I do an Attribute GR&R study?

1. **Identify thirty to 100 items to be evaluated.**
    - Typically more samples are needed in an attribute study because of the nature of data.
2. **Have a person who has knowledge of the customer requirements for this characteristic rate these items on the scale that is used in daily operations.**
    - Record their responses for all thirty to 100 items in a column of data called "attribute" or "reference standard."
3. **Identify the people who need to measure the items.**
4. **Have the first person rate all thirty to 100 items in random order and record these values.**
    - Repeat this step for each subsequent person, recording this data.
5. **Repeat step four such that each operator has a chance at a repeat measure and record this data.**

Several important measures from this test are identified in the following example.

Attribute GR&R Measures

Known Population		Operator #1		Operator #2		Operator #3	
Sample	**Attribute**	**Try #1**	**Try #2**	**Try #1**	**Try #2**	**Try #1**	**Try #2**
1	pass ②	pass	pass	pass ①	pass	fail	fail
2	pass	pass	pass	pass	pass	fail	fail
3	fail	fail	fail	fail ③	pass	fail	fail
4	fail	fail	fail	fail	fail	fail	fail
5	fail	fail	fail	pass	fail	fail	fail
6	pass	pass	pass ④	pass	pass	pass	pass

1. The number of times an operator can repeat the measured value. If an operator measured thirty items twice and successfully repeated the measures twenty-six times, then he or she had an 86.6% success rate. Each operator will have a success rate for their repeat measures.

2. The number of times an operator not only repeats the measures, but these repeats match the known standard. Although an operator may have successfully repeated their measures 86.6% of the time, the measure may have only matched the known standard twenty-three times out of thirty, for a 76.6% success rate. This implies that an operator may not understand the criteria for the known standard.

3. The number of times all of the operators match their repeat measures. If three operators evaluate thirty parts and all of the operators match their repeats twenty-two times, then this is a 73.3% success rate.

4. The number of times all of the operators match their repeat measures and all these measures match the known standards. If three operators match all of these measures twenty times out of thirty, then this is a success rate of 66.6%.

This last measure is the measure used to determine the effectiveness of the measurement system. In general, it should be greater than 80% (preferably 90%), assuming that the study was done with three operators and two trials. If the value is less than 80%, then opportunities for improvement need to be identified. Typically, the solution is either training of the operators, better definition of the known standard, or an improvement to the environment in the area where the item is being measured.

Example:

When a customer places an order, a system operator is responsible for finding information in a database and then transferring that information to the order form. Recently, customers have been receiving the wrong product, and the data suggests that the problem may be in transferring this information. For the Black Belt to determine the capability of this process, an Attribute GR&R must first be conducted. To do this, the Black Belt creates thirty different fake orders, with known correct answers. Next the operators are asked to find the required information in the database to determine whether the operators can get the correct answer or not. The answers to this test are included in the following chart.

Attribute GR&R Effectiveness

Known Population		Operator #1		Operator #2		Operator #3		Agree *	Agree **
Sample #	Attribute	Try #1	Try #2	Try #1	Try #2	Try #1	Try #2	Y/N	Y/N
1	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Y	Y
2	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Y	Y
3	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Y	Y
4	Pass	Pass	Pass	Pass	Pass	Fail	Pass	Y	Y
5	Fail	Fail	Fail	Fail	Fail	Pass	Fail	N	N
6	Fail	Pass	Pass	Pass	Pass	Pass	Pass	N	N
7	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Y	N
8	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Y	Y
27	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Y	Y
28	Pass	Pass	Pass	Pass	Pass	Pass	Fail	Y	Y
29	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Y	Y
30	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Y	Y
	% Appraiser Score		100.00%		100.00%		83.33%		
	%Score vs. Attribute		93.33%		96.67%		80.00%		
							Screen % Effective Score	80.00%	
							Screen % Effective Score vs. Attribute		76.67%

* All operators agree with themselves and each other.

**All operators agree with themselves and each other, and with the standard.

Note:

- The target for all scores is 100%. Less than 80% is a reasonable lower limit for most cases.
- The % Appraiser Score is the repeatability and shows when the operator agrees with himself/herself on both trials.
- The % Score vs. Attribute is a score of the individual error against a known population and shows when the operator agrees on both trials with the known standard.
- The Screen % Effective score shows when all operators agreed within and between themselves.
- The Screen % Effective vs. Attribute is the total error against a known population and shows when all operators agreed with and between themselves *and* agreed with the known standard.

According to these results, the measurement system is unacceptable because the screen % effective score vs. attribute is less than 80%.

Capability Indices

Why use it?

Process capability refers to the capability of a process to consistently make a product that meets a customer-specified specification range (tolerance). Capability indices are used to predict the performance of a process by comparing the width of process variation to the width of the specified tolerance. It is used extensively in many industries and only has meaning if the process being studied is stable (in statistical control).

What does it do?

Capability indices allow calculations for both short-term (C_p and C_{pk}) and/or long-term (P_p and P_{pk}) performance for a process whose output is measured using variable data at a specific opportunity for a defect.

Short-Term Capability Indices

The short-term capability indices C_p and C_{pk} are measures calculated using the short-term process standard deviation. Because the short-term process variation is used, these measures are free of subgroup drift in the data and take into account only the *within subgroup* variation.

C_p is a ratio of the customer-specified tolerance to six standard deviations of the short-term process variation. C_p is calculated without regard to location of the data mean within the tolerance, so it gives an indication of what the process could perform to if the mean of the data was centered between the specification limits. Because of this assumption, C_p is sometimes referred to as the process potential.

C_{pk} is a ratio of the distance between the process average and the closest specification limit, to three standard deviations of the short-term process variation. Because C_{pk} takes into account location of the data mean within the tolerance, it is a more realistic measure of the process capability. C_{pk} is sometimes referred to as the process performance.

Long-Term Capability Indices

The long-term capability indices P_p and P_{pk} are measures calculated using the long-term process standard deviation. Because the long-term process variation is used, these measures take into account subgroup drift in the data as well as the *within subgroup* variation.

P_p is a ratio of the customer-specified tolerance to six standard deviations of the long-term process variation. Like C_p, P_p is calculated without regard to location of the data mean within the tolerance.

P_{pk} is a ratio of the distance between the process average and the closest specification limit, to three standard deviations of the long-term process variation. Like C_{pk}, P_{pk} takes into account the location of the data mean within the tolerance. Because P_{pk} uses the long-term variation in the process and takes into account the process centering within the specified tolerance, it is a good indicator of the process performance the customer is seeing.

What is a good C_p/C_{pk} or P_p/P_{pk} value?

Because both C_p and C_{pk} are ratios of the tolerance width to the process variation, larger values of C_p and C_{pk} are better. The larger the C_p and C_{pk}, the wider the tolerance width relative to the process variation. The same is also true for P_p and P_{pk}.

What determines a "good" value depends on the definition of "good." A C_p of 1.33 is approximately equivalent to a short-term Z of 4. A P_{pk} of 1.33 is approximately equivalent to a long-term Z of 4. However, a Six Sigma process typically has a short-term Z of 6 or a long-term Z of 4.5.

How do I do it?

The type of data available (short-term or long-term) will determine whether C_p / C_{pk} or P_p / P_{pk} can be calculated. The following mathematical formulas are used to calculate these indices.

$$C_p = (USL - LSL)/6\sigma_{st}$$

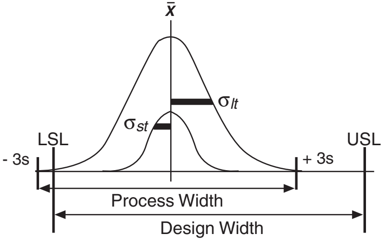
Where σ_{st} = short-term pooled standard deviation.

$$P_p = (USL - LSL)/6\sigma_{lt}$$

Where σ_{lt} = long-term standard deviation.

Capability Indices

Short-term Capability Indices	**Long-term Capability Indices**
$C_p = \dfrac{USL - LSL}{6\ \sigma_{st}}$	$P_p = \dfrac{USL - LSL}{6\ \sigma_{lt}}$
$C_{pk} = \min(C_{pk(USL)}, C_{pk\ (LSL)})$	$P_{pk} = \min(P_{pk(USL)}, P_{pk\ (LSL)})$
$C_{pk(USL)} = \dfrac{(USL - \bar{X})}{3\ \sigma_{st}}$	$P_{pk(USL)} = \dfrac{(USL - \bar{X})}{3\ \sigma_{lt}}$
$C_{pk(LSL)} = \dfrac{(\bar{X} - LSL)}{3\ \sigma_{st}}$	$P_{pk(LSL)} = \dfrac{(\bar{X} - LSL)}{3\ \sigma_{lt}}$



Manufacturing Example:

Suppose the diameter of a spark plug is a critical dimension that needs to conform to lower and upper customer specification limits of 0.480" and 0.490", respectively. Five randomly selected spark plugs are measured in every work shift. Each of the five samples on each work shift is called a subgroup. Subgroups have been collected for three months on a stable process. The average of all the data was 0.487". The short-term standard deviation has been calculated and was determined to be 0.0013". The long-term standard deviation was determined to be 0.019".

To Calculate C_p and C_{pk}:

$$C_p = (0.490'' - 0.480'')/(6 \times 0.0013) = 0.010/0.0078 = 1.28$$

$$C_{pl} = (0.487 - 0.480)/(3 \times 0.0013) = 0.007/0.0039 = 1.79$$

$$C_{pu} = (0.490 - 0.487)/(3 \times 0.0013) = 0.003/0.0039 = 0.77$$

$$C_{pk} = \min(C_{pl}, C_{pu})$$

$$C_{pk} = \min(1.79, 0.77) = 0.77$$

To Calculate P_p and P_{pk}:

$$P_p = (0.490'' - 0.480'')/(6 \times 0.019) = 0.0100/0.114 = 0.09$$

$$P_{pl} = (0.487 - 0.480)/(3 \times 0.019) = 0.007/0.057 = 0.12$$

$$P_{pu} = (0.490 - 0.487)/(3 \times 0.019) = 0.003/0.057 = 0.05$$

$$P_{pk} = \min(P_{pl}, P_{pu})$$

$$P_{pk} = \min(0.12, 0.05) = 0.05$$

In this example, C_p is 1.28. Because C_p is the ratio of the specified tolerance to the process variation, a C_p value of 1.28 indicates that the process is capable of delivering product that meets the specified tolerance (if the process is centered). (A C_p greater than 1 indicates the process can deliver a product that meets the specifications at least 99.73% of the time.) Any improvements to the process to increase our value of 1.28 would require a reduction in the variability within our subgroups. C_p, however, is calculated without regard to the process centering within the specified tolerance. A centered process is rarely the case so a C_{pk} value must be calculated.

C_{pk} considers the location of the process data average. In this calculation, we are comparing the average of our process to the closest specification limit and dividing by three short-term standard deviations. In our example, C_{pk} is 0.77. In contrast to the C_p measurement, the C_{pk} measurement clearly shows that the process is incapable of producing product that meets the specified tolerance. Any improvements to our process to increase our value of 0.77 would require a mean shift in the data towards the center of the tolerance and/or a reduction in the *within subgroup* variation. (**Note**: For centered processes, C_p and C_{pk} will be the same.)

Our P_p is 0.09. Because P_p is the ratio of the specified tolerance to the process variation, a P_p value of 0.09 indicates that the process is incapable of delivering product that meets the specified tolerance. Any improvements to the process to increase our value of 0.09 would require a reduction in the variability within and/or between subgroups. P_p, however, is calculated without regard to the process centering within the specified tolerance. A centered process is rarely the case so a P_{pk} value, which accounts for lack of process centering, will surely indicate poor capability for our process as well. (**Note**: For both P_p and C_p, we assume no drifting of the subgroup averages.)

P_{pk} represents the actual long-term performance of the process and is the index that most likely represents what customers receive. In the example, P_{pk} is 0.05, confirming our P_p result of poor process performance. Any improvements to the process to increase our value of 0.05 would require a mean shift in the data towards the center of the tolerance and/or a reduction in the *within subgroup* and *between subgroup* variations.

Business Process Example:

Suppose a call center reports to its customers that it will resolve their issue within fifteen minutes. This fifteen-minute time limit is the upper specification limit. It is desirable to resolve the issue as soon as possible; therefore, there is no lower specification limit. The call center operates twenty-four hours a day in eight-hour shifts. Six calls are randomly measured every shift and recorded for two months. An SPC chart shows the process is stable. The average of the data is 11.7 minutes, the short-term pooled standard deviation is 1.2 minutes, and the long-term standard deviation is 2.8 minutes.

To Calculate C_p and C_{pk}:

$$C_p = \text{cannot be calculated as there is no LSL}$$

$$C_{pl} = \text{undefined}$$

$$C_{pu} = (15 - 11.7)/(3 \times 1.2) = 3.3/3.6 = 0.92$$

$$C_{pk} = \min(C_{pl}, C_{pu}) = 0.92$$

To Calculate P_p and P_{pk}:

$$P_p = \text{cannot be calculated as there is no LSL}$$

$$P_{pl} = \text{undefined}$$

$$P_{pu} = (15 - 11.7)/(3 \times 2.8) = 3.3/8.4 = 0.39$$

$$P_{pk} = \min(P_{pl}, P_{pu}) = 0.39$$

In this example, we can only evaluate C_{pk} and P_{pk} as there is no lower limit. These numbers indicate that if we can eliminate *between subgroup* variation, we could achieve a process capability (P_{pk}) of 0.92, which is our current C_{pk}.

Graphical Analysis

Why use it?

Graphical analysis is an effective way to present data.

What does it do?

Graphs allow an organization to represent data (either variable or attribute) to evaluate central tendency and spread, detect patterns in the data, and identify sources of variation in the process.

How do I do it?

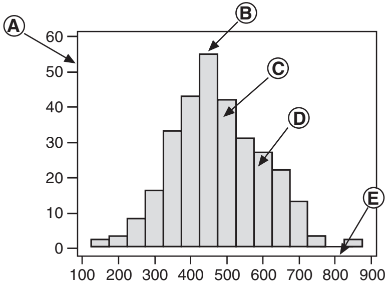
The type of data collected will determine the type of graph used to represent the data. Described below are some common graphs for different data types.

Histograms

Histograms are an efficient graphical method for describing the distribution of data. However, a large enough sample (greater than fifty data points) is required to effectively show the distribution. Data is divided into groups called "classes." The number of data points within a class is counted and bars are drawn for each class. The shape of the resultant histogram can be used to assess:

- Measures of central tendency,
- Variation in the data,
- Shape or underlying distribution of the data (when compared to a normal distribution).

A Histogram



A. The vertical axis shows the frequency or percentage of data points in each class.

B. The modal class is the class with the highest frequency.

C. The frequency is the number of data points found in each class.

D. Each bar is one class or interval.

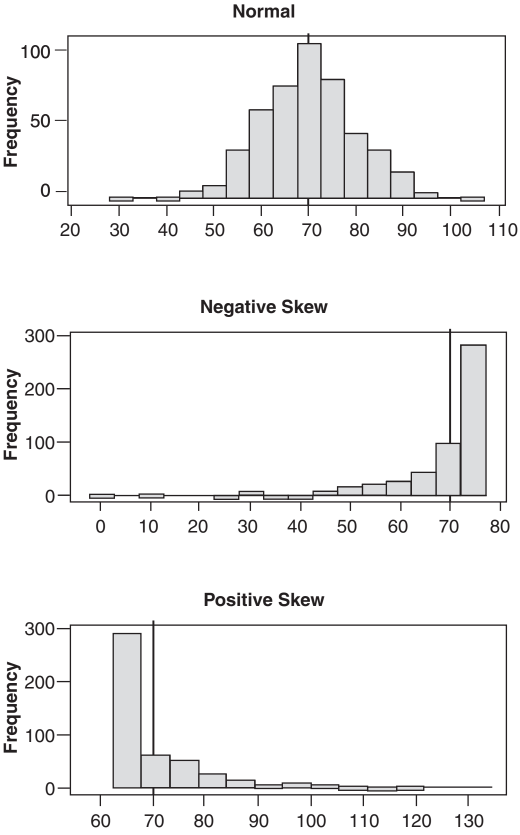
E. The horizontal axis shows the scale of measure for the Critical To characteristics.

Software packages are available that will automatically calculate the class intervals and allow the user to revise them as required. The number of intervals shown can influence the pattern of the sample.

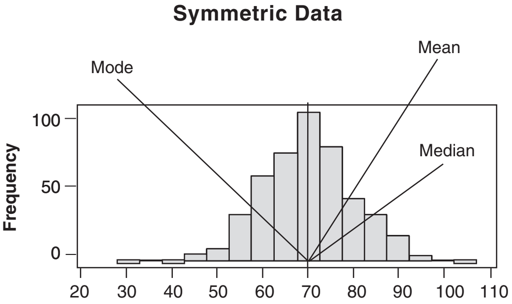
Plotting the data is always recommended. Three unique distributions of data are shown on the following page. All three data plots share an identical mean, but the spread of the data about the mean differs significantly.

> ***Tip*** Always look for twin or multiple peaks indicating that the data comes from two or more sources (e.g., machines, shifts, people, suppliers). If multiple peaks are evident, the data must then be stratified.

Three Distributions of Data

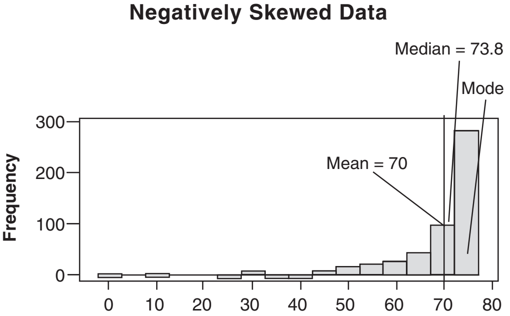


The following histogram illustrates a distribution where the measures of central tendency (mean, median, and mode) are equal.



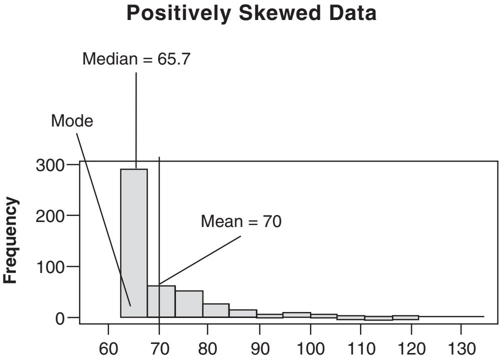
This is a normal distribution, sometimes referred to as a bell-shaped curve. Notice that there is a single point of central tendency and the data are symmetrically distributed about the center.

Some processes are naturally skewed. A negatively skewed distribution is shown in the following figure:



For skewed-left data, the median is between the mode and mean, with the mean on the left. This distribution does not appear normally distributed and may require transformation prior to statistical analysis. Data that sometimes exhibit negative skewness are cash flow, yield, and strength.

A positively skewed distribution is shown in the following figure:

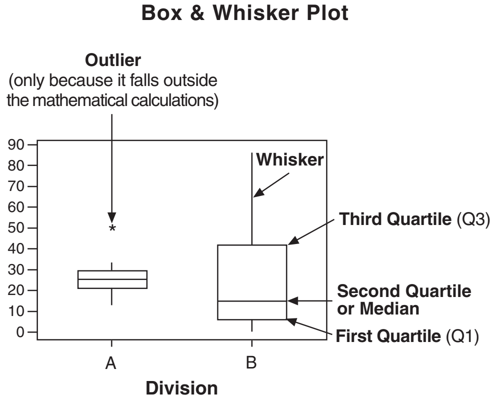


The long tail of the skewed distribution points in the positive x-direction. The median is between the mode and the mean, with the mean on the right. This distribution is not normally distributed and is another candidate for transformation. Data that sometimes exhibit positive skewness are home prices, salaries, cycle time of delivery, and surface roughness.

(For more information on histograms, refer to *The Memory Jogger™II*.)

Box and Whisker Plot

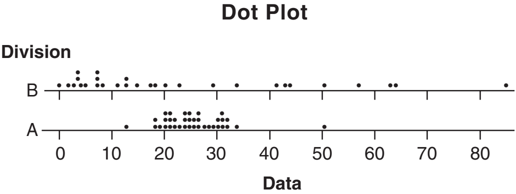
A box and whisker plot can be used to view variability and centering, based on quartiles, in a variable output (y) vs. an attribute input (x) at one or more levels.



- *Quartiles* rank-order the data and identify the twenty-fifth, fiftieth, and seventy-fifth percentile.
- The *Interquartile (IQ) Range* is equal to the range between the first and third quartile (Q3 - Q1).
- *Whiskers* are limited by a mathematical calculation. The upper whisker cannot be longer than Q3 + 1.5 x (Q3 - Q1). The whisker line is drawn to the largest value in the data set *below* this calculated value. If there are data points above this value, they show up as asterisks to indicate they may be outliers. The same is true for the lower whisker with a limit of Q1 - 1.5 x (Q3 - Q1). The whisker line is then drawn to the smallest value in the data set *above* this calculated value.

Dot Plot

The dot plot shows variability in a sample of variable or attribute data. Multiple dot plots can be constructed for discrete levels of another variable.



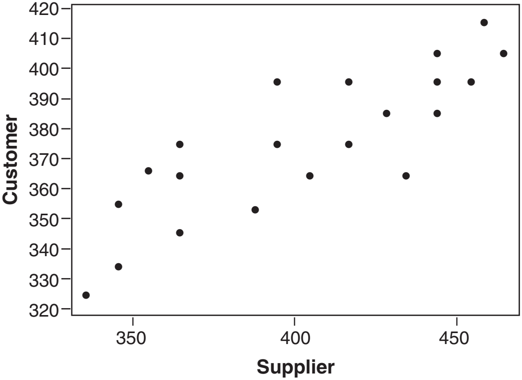
Multiple occurrences are stacked vertically along the x axis. Notice how the discrete levels for Divisions A and B lay above one another, making the dot plot an effective tool for comparing central location and variability within and between divisions.

Scatter Diagram

The scatter diagram is used to determine whether a qualitative relationship, linear or curvilinear, exists between two continuous or discrete variables. Scatter diagrams provide verification of a Cause & Effect Diagram or Matrix to determine if there is more than just a consensus connection between causes and effects.

The scatter diagram on the following page shows a strong positive relationship between the number of customers and the number of suppliers; as the number of customers increases, so does the number of suppliers.

Scatter Diagram



Subsequent analysis such as correlation and regression are typically used to quantify the relationship in a scatter diagram.

> **Tip** The scatter diagram does not predict cause and effect relationships; it only shows the strength of the relationship between two variables. The stronger the relationship, the greater the likelihood that change in one variable will affect change in another variable.

(For more information on scatter diagrams, refer to *The Memory Jogger™II*.)

Run Chart

Why use it?

Run Charts allow a team to study observed data (a performance measure of a process) for trends or patterns over a specified period of time.

What does it do?

A Run Chart:

- Monitors the performance of one or more processes over time to detect trends, shifts, or cycles.
- Allows a team to compare a performance measure before and after implementation of a solution, to measure its impact.
- Focuses attention on truly vital changes in the process.
- Tracks useful information for predicting trends.

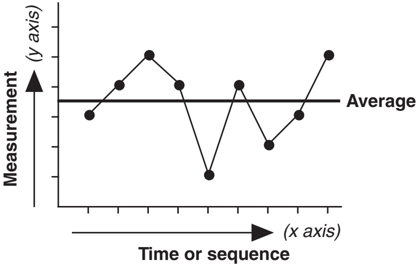
How do I do it?

1. **Decide on the process performance measure.**
2. **Gather data.**
   - Generally, 20-25 data points should be collected to detect meaningful patterns.
3. **Create a graph with a vertical line (y axis) and a horizontal line (x axis).**
   - On the vertical line (y axis), draw the scale related to the variable being measured.
     - Arrange the y axis to cover the full range of the measurements and then some (e.g., $1^{1}/_{2}$ times the range of data).
   - On the horizontal line (x axis), draw the time or sequence scale.

4. Plot the data.

- Look at the data collected. If there are no obvious trends, calculate the average or arithmetic mean. The average is the sum of the measured values divided by the number of data points. (The median value can also be used but the mean is the most frequently used measure of the "centering" of the sample.) Draw a horizontal line at the average value.

Tip Do not redraw this average line every time new data is added. Only when there has been a significant change in the process or prevailing conditions should the average be recalculated and redrawn, and then only using the data points after the verified change.

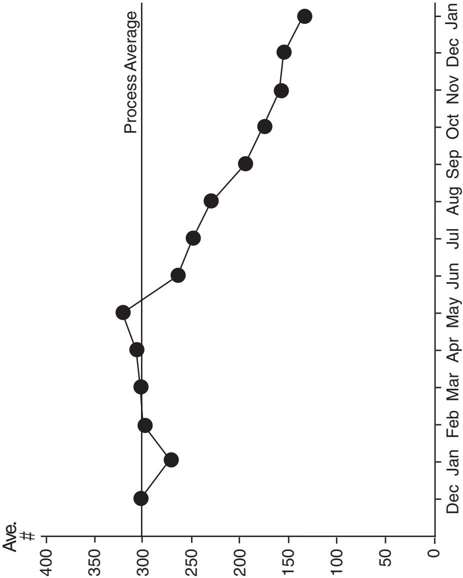


5. Interpret the chart.

- Note the position of the average line. Is it where it should be relative to a customer need or specification? Is it where the organization wants it to be, relative to the business objective?

Tip A danger in using a Run Chart is the tendency to see every variation in data as being important. The Run Chart should be used to focus on truly vital changes in the process. Simple tests can be used to look for meaningful trends and patterns. (These tests are found in the "Determining if the Process is Out of Control" section of the Control Charts chapter of this book. Remember that for more sophisticated uses, a Control Chart is invaluable because it is simply a Run Chart with statistically based limits.)

Average Number of Days for Determining Eligibility for Services



Information provided courtesy of Georgia State Department of Human Resources, Division of Rehabilitation Services

Note: Eligibility requirements changed in May, making it much simpler for the department staff to make determinations. The trend is statistically significant because there are six or more consecutive points declining.

Pareto Chart

Why use it?

A Pareto Chart focuses efforts on the problems that offer the greatest potential for improvement by showing their relative frequency or size in a descending bar graph.

What does it do?

A Pareto Chart:

- Helps a team focus on those causes that will have the greatest impact if solved.
- Is based on the proven Pareto principle: 20% of the sources cause 80% of any problem.
- Displays the relative importance of problems in a simple, quickly interpreted, visual format.
- Helps prevent "shifting the problem" where the "solution" removes some causes but worsens others.
- Measures progress in a highly visible format that provides incentive to push on for more improvement.

How do I do it?

1. **Decide which problem to focus on.**
2. **Using brainstorming or existing data, choose the causes or problems that will be monitored, compared, and rank-ordered.**
    - A brainstorming session may ask "What are typical problems that users ask about a telephone help line?" Questions based on existing data may ask, "What problems in the last month have users called in to the help line?"

3. **Choose the most meaningful unit of measurement such as frequency or cost.**

   - Sometimes it is difficult to know before the study is done which unit of measurement is best. Be prepared to do both frequency and cost.

4. **Choose the time period for the study.**

   - Choose a time period that is long enough to represent the situation. Longer studies don't always translate to better information. Look first at volume and variety within the data.

   - Make sure the scheduled time is typical in order to take into account seasonality or even different patterns within a given day or week.

5. **Gather the necessary data on each problem category either by "real time" or reviewing historical data.**

   - Whether data is gathered in real time or historically, CheckSheets are the easiest method for collecting data.

   Tip *Always* include with the source data and the final chart, the identifiers that indicate the source, location, and time period covered.

6. **Compare the relative frequency or cost of each problem category.**

7. **List the problem categories on a horizontal line and frequencies on a vertical line.**

   - List the categories in descending order from left to right on the horizontal line with bars above each problem category to indicate its frequency or cost. List the unit of measure on the vertical line.

8. **(Optional) Draw the cumulative percentage line showing the portion of the total that each problem category represents.**

   a) On the vertical line (opposite the raw data, #, $, etc.), record 100% opposite the total number and 50% at the halfway point. Fill in the remaining percentages drawn to scale.

b) Starting with the highest problem category, draw a dot or mark an x at the upper righthand corner of the bar.

- Add the total of the next problem category to the first and draw a dot above that bar showing both the cumulative number and percentage. Connect the dots and record the remaining cumulative totals until 100% is reached.

9. **Interpret the results.**

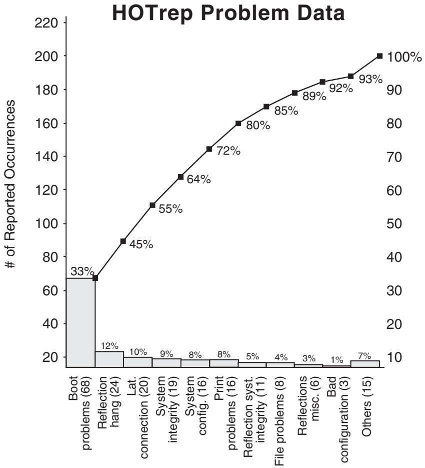
- Generally, the tallest bars indicate the biggest contributors to the overall problem. Dealing with these problem categories first therefore makes common sense. *But the most frequent or expensive is not always the most important.* Always ask, What has the most impact on the goals of our business and customers?

Example:

Consider the case of HOTrep, an internal computer network help line. The parent organization wanted to know what problems the people calling in to the HOTrep help line were experiencing. A team was created to brainstorm possible problems to monitor for comparison. They choose frequency as the most important measure because the project team could use this information to simplify software, improve documentation or training, or solve bigger system problems. HOTrep help line calls were reviewed for ten weeks and data from these calls was gathered based on a review of incident reports (historical data).

Problem Category	**Frequency**	**Percent (%)**
Bad configuration	3	1
Boot problems	68	33
File problems	8	4
Lat. connection	20	10
Print problems	16	8
Reflection hang	24	12
Reflection sys. integrity	11	5
Reflections misc.	6	3
System configuration	16	8
System integrity	19	9
Others	15	7
Total	**206**	

The data was displayed in a Pareto Chart and helped the team determine that it should focus on "Boot problems," to have the greatest impact on its customers.



Information provided courtesy of SmithKline Beecham

Variations

The Pareto Chart is one of the most widely and creatively used improvement tools. The variations used most frequently are:

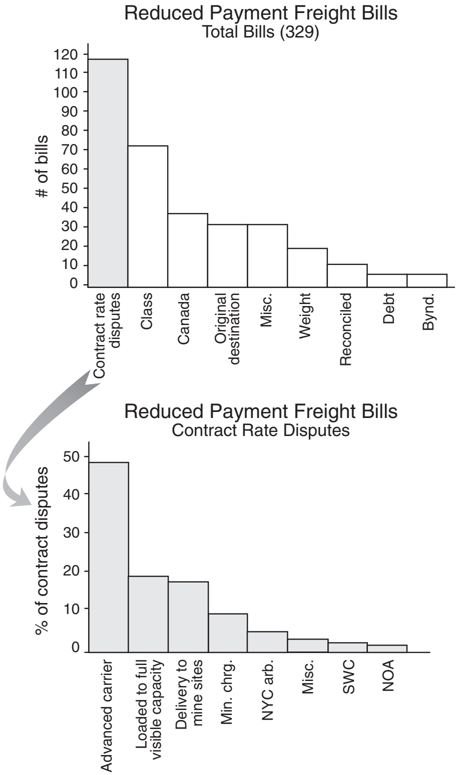
A. *Major Cause Breakdowns* in which the "tallest bar" is broken into subcauses in a second, linked Pareto.

B. *Before and After* in which the "new Pareto" bars are drawn side by side with the original Pareto, showing the effect of a change. It can be drawn as one chart or two separate charts.

C. *Change the Source of Data* in which data is collected on the same problem but from different departments, locations, equipment, and so on, and shown in side-by-side Pareto Charts.

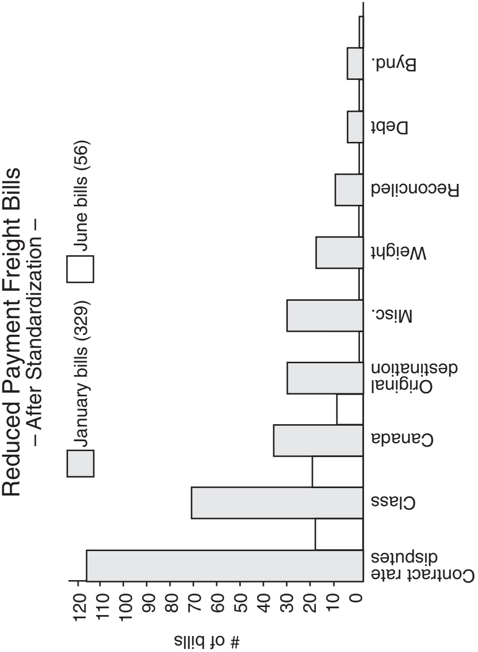
D. *Change Measurement Scale* in which the same categories are used but measured differently. Typically "cost" and "frequency" are alternated.

A. Major Cause Breakdowns



Information provided courtesy of Goodyear

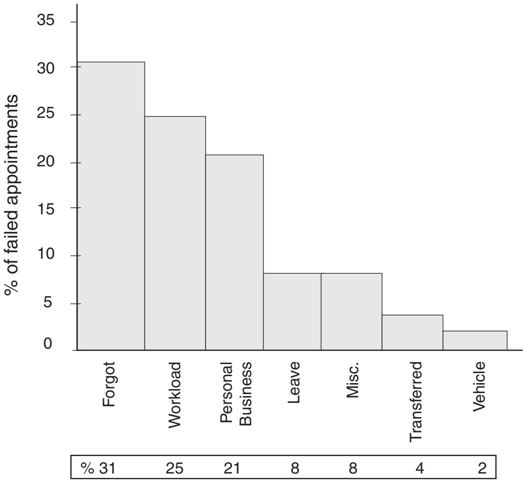
B. Before and After



Information provided courtesy of Goodyear

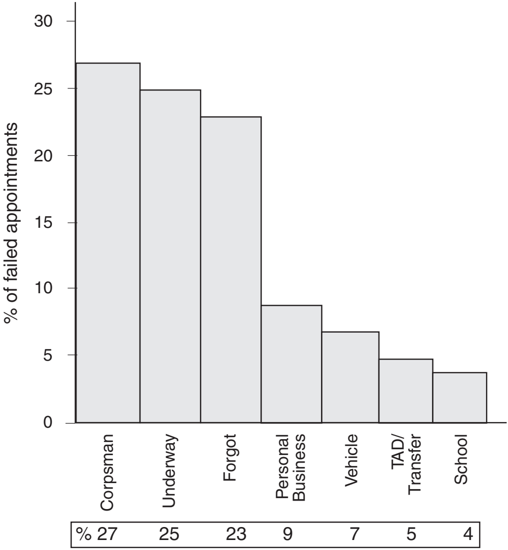
C. Change the Source of Data

Reason for Failed Appointments
Source of Data is: Shore-Based Command



Information provided courtesy of U.S. Navy, Naval Dental Center, San Diego

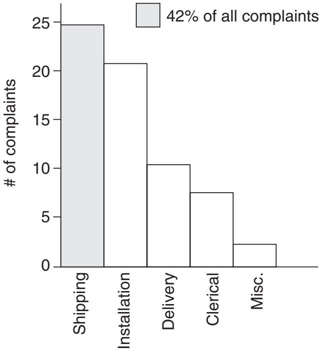
C. Change the Source of Data


Reason for Failed Appointments
Source of Data is: Ship-Based Command

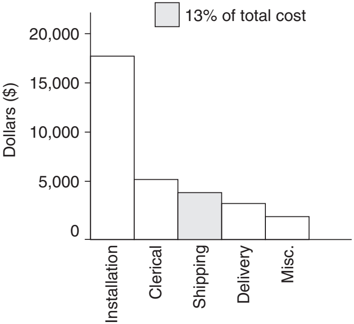
Information provided courtesy of
U.S. Navy, Naval Dental Center, San Diego

D. Change Measurement Scale

Field Service Customer Complaints



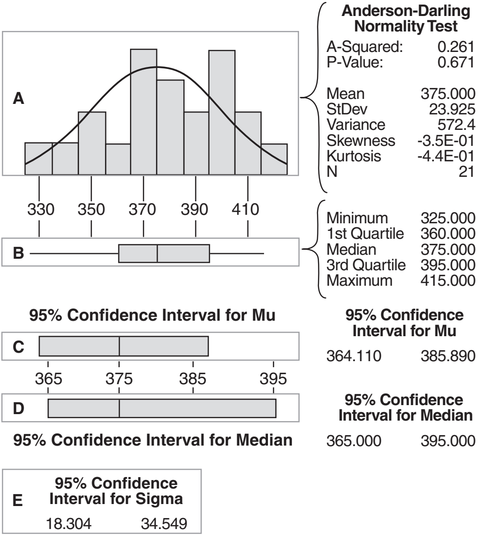
Cost to Rectify Field Service Complaints



Graphical Summary

Graphical summary is a tool that can be used to summarize a collection of individual observations for a continuous variable. Quantitative inferences about the data set can be made by analyzing the many statistics that a graphical summary provides. Most common statistical programs provide some version of a graphical summary; the following summary comes from MINITAB™ software.

Graphical Summary



```
Anderson-Darling
 Normality Test
A-Squared:      0.261
P-Value:        0.671

Mean          375.000
StDev          23.925
Variance        572.4
Skewness     -3.5E-01
Kurtosis     -4.4E-01
N                  21

Minimum       325.000
1st Quartile  360.000
Median        375.000
3rd Quartile  395.000
Maximum       415.000

 95% Confidence
 Interval for Mu
364.110       385.890

 95% Confidence
Interval for Median
365.000       395.000

 95% Confidence
Interval for Sigma
18.304        34.549
```

The data from the graphs shows a representative sample of the population. Described below is the information contained in the summary.

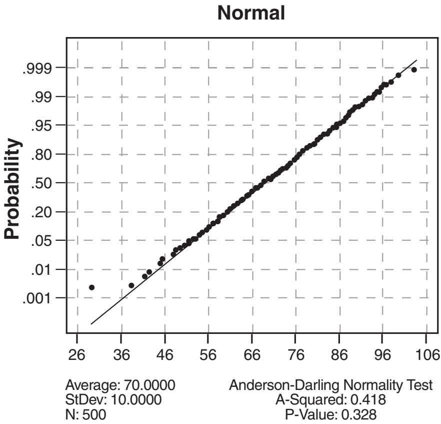
- *Figure A* - The bell-shaped curve is a normal curve (determined by the average and standard deviation of the data) and assumes normality. The bars in the histogram are the actual data. Shown to the right of the figure is the summary information. (N is the number of observations.)
    - Anderson-Darling Normality Test: If the p-value is equal to or less than a specified alpha (α) risk, there is evidence that the data does not follow a normal distribution. Because the p-value is greater than 0.05 (the typical α risk), the results of this analysis suggest that the data is normally distributed.
    - Kurtosis is a measure of the peakedness of the curve (thinner or thicker). Departures from zero can indicate non-normality. Positive kurtosis indicates a greater peak than normal. Negative kurtosis indicates a flatter peak. This example is very near zero.
- *Figure B* - This box and whisker plot displays the variability based on rank-ordering the twenty-one observations into quartiles.
- *Figure C* - The 95% Confidence Interval for Mu is an interval that can be said, with 95% certainty, to contain the true value of the population mean.
- *Figure D* - The 95% Confidence Interval for Median is an interval that can be said, with 95% certainty, to contain the true value of the population median.

- *Figure E* - The 95% Confidence Interval for Sigma is an interval that can be said, with 95% certainty, to contain the true value of the population standard deviation.

Normal Probability Plot

A normal probability plot (NPP) is used to graphically and analytically perform a hypothesis test to determine if the population distribution is normal. The NPP is a graph of calculated normal probabilities vs. a data scale. A best-fit line simulates a cumulative distribution function for the population from which the data is taken. Data that is normally distributed will appear on the plot as a straight line.

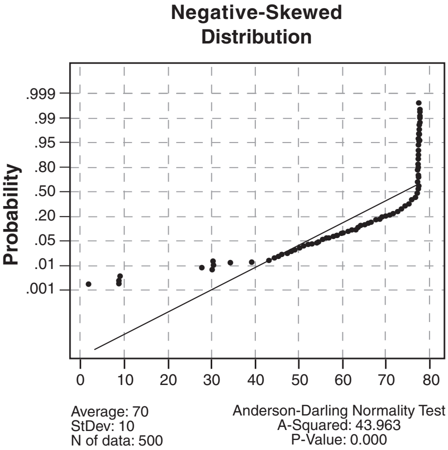
Normal Probability Plots



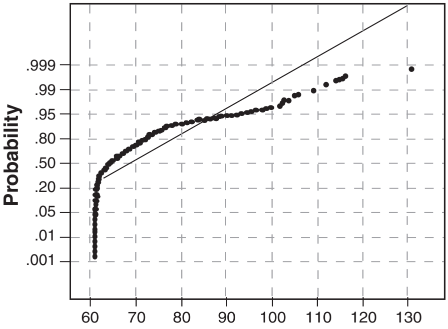
One can also interpret the analytical output from an Anderson-Darling Test. If the p-value is less than the α risk, the data is not from a normal distribution.

In the example output on the previous page from MINITAB software, the plotted points fall very close to the best-fit line. In addition, the p-value (0.328) is greater than the α risk (0.05). Therefore, the data in this example is from a normal distribution.

Additional distributions have been plotted below. Notice the departure of the plotted data from the line for the positive-skewed and negative-skewed distributions. Accordingly, the p-value is less than the α risk, indicating that this data may not be from a normal parent distribution.



Positive-Skewed Distribution



Average: 70
StDev: 10
N of data: 500

Anderson-Darling Normality Test
A-Squared: 46.447
P-Value: 0.000

Multi-Vari Charts

Why use it?

Multi-Vari charts are practical graphical tools that illustrate how variation in the input variables (x's) impacts the output variable (y) or response. These charts can help screen for possible sources of variation (x's). There are two types of Multi-Vari studies: 1) Passive nested studies, which are conducted without disrupting the routine of the process, and 2) Manipulated crossed studies, which are conducted by intentionally manipulating levels of the x's. Sources of variation can be either controllable and/or noise variables. Categorical x's are very typical for Multi-Vari studies (i.e., short vs. long, low vs. high, batch A vs. batch B vs. batch C). Multi-Vari studies help the organization determine where its efforts should be focused.

What does it do?

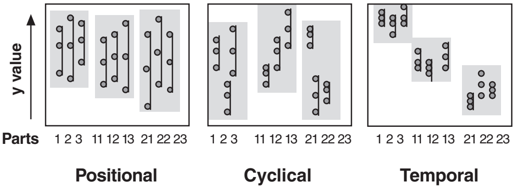
Given either historic data or data collected from a constructed sampling plan, a Multi-Vari study is a visual comparison of the effects of each of the factors by displaying, for all factors, the means at each factor level. It is an efficient graphical tool that is useful in reducing the number of candidate factors that may be impacting a response (y) down to a practical number.

Nested Designs

Sources of variation for a passive nested design might be:

- Positional (i.e., within-piece variation).
- Cyclical (i.e., consecutive piece-to-piece variation).
- Temporal (time-to-time variation, i.e., shift-to-shift or day-to-day).

Types of Variation in Nested Designs



The y axis in this figure records the measure of performance of units taken at different periods of time, in time-order sequence. Each cluster (shaded box) represents three consecutive parts, each measured in three locations. Each of the three charts represents a different process, with each process having the greatest source of variation coming from a different component. In the Positional Chart, each vertical line represents a part with the three dots recording three measurements taken on that part. The greatest variation is within the parts. In the Cyclical Chart, each cluster represents three consecutive parts. Here, the greatest variation is shown to be between consecutive parts. The third chart, the Temporal Chart, shows three clusters representing three different shifts or days, with the largest variation between the clusters.

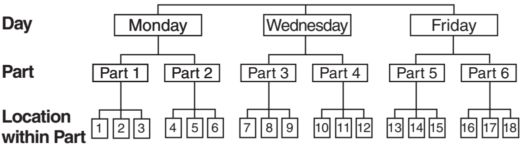
Nested Multi-Vari Example:

In a nested Multi-Vari study, the positional readings taken were nested within a part. The positions within part were taken at random and were unique to that part; position 1 on part 1 was not the same as position 1 on part 2.

The subgroups of three "consecutive parts" were nested within a shift or day. The parts inspected were unique to that shift or day.

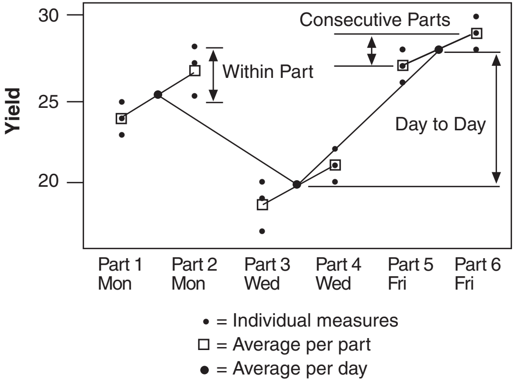
A sampling plan or hierarchy was created to define the parameters in obtaining samples for the study.

Sampling Plan for a Nested Design



A passive nested study was conducted in which two consecutive parts (cyclical) were measured over three days (temporal). Each part was measured in three locations, which were randomly chosen on each part (positional). A nested Multi-Vari chart was then created to show the results.

Nested Multi-Vari Chart



Day-to-day variation appears to be the greatest source of variation, compared to the variation within part or part-to-part within a day (consecutive parts). The next step in this study would be to evaluate the process parameters that impact day-to-day variation i.e., what changes (different material lots/batches, environmental factors, etc.) are occurring day to day to affect the process.

Crossed Designs:

Sources of variation for a manipulated crossed design might be:

- Machine (A or B).
- Tool (standard or carbide).
- Coolant (off or on).

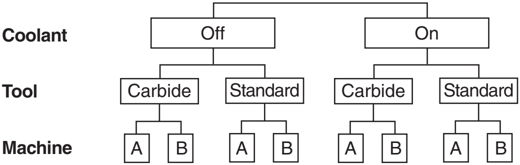
Interactions can only be observed with crossed studies. When an interaction occurs, the factors associated with the interaction must be analyzed together to see the effect of one factor's settings on the other factor's settings.

With fully crossed designs, the data may be reordered and a chart may be generated with the variables in different positions to clarify the analysis. In contrast, passive nested designs are time-based analyses and therefore must maintain the data sequence in the Multi-Vari chart.

Crossed Design Example:

A sampling plan or hierarchy for a crossed design is shown below:

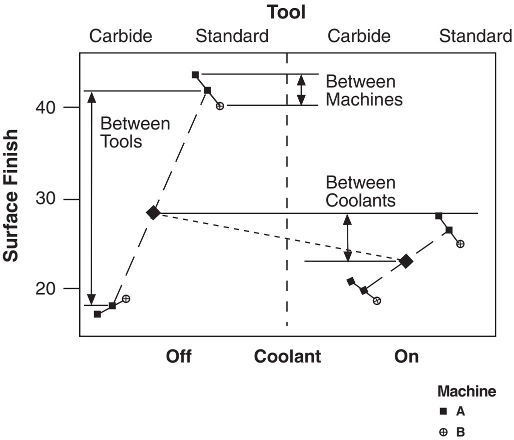
Sampling Plan for a Crossed Design



The coolant was turned "on" or "off" for each of two tools while the tools were being used on one of two machines. Every possible combination was run using the same two machines, the same two types of tools, and the same two coolant settings.

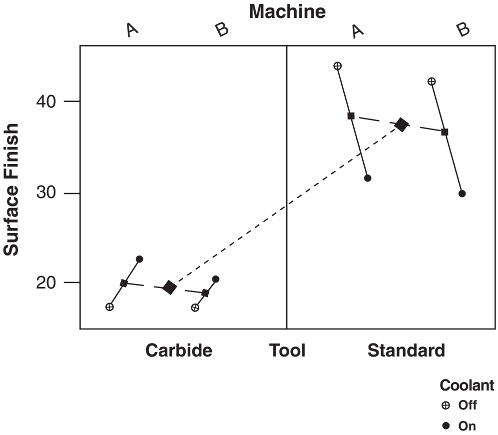
The following chart uses these sources to investigate graphically the main effects and interactions of these factors in improving surface finish (lower is better).

Crossed Multi-Vari Chart



It appears that the best (lowest) value occurs with carbide tools using no coolant. The different machines have a relatively small impact. It may also be noted that when the coolant is off, there is a large difference between the two tool types. Because of the crossed nature of this study, we would conclude that there is an interaction between coolant and tool type.

Crossed Multi-Vari Chart with Different Sorting



The interaction is also apparent in this second chart, which shows the same data but different sorting. Coolant "off" and "carbide tool" are again the lowest combinations. Notice how coolant "on" is now the lowest combination with the standard tool. Hence, an interaction could also be expected here.

How do I create a Multi-Vari chart?

Multi-Vari charts are easiest done with a computer, but not difficult to do by hand.

1. **Plan the Multi-Vari Study.**
   - Identify the y to be studied.
   - Determine how the y will be measured and validate the measuring system.

- Identify the potential sources of variation. For nested designs, the levels depend on passive data; for crossed designs, the levels are specifically selected for manipulation.
- Create a balanced sampling plan or hierarchy of sources. Balance refers to equal numbers of samples within the upper levels in the hierarchy (i.e., two tools for each machine). A strict balance of exactly the same number of samples for each possible combination of factors, while desirable, is not an absolute requirement. However, there must be at least one data point for each possible combination.
- Decide how to collect data in order to distinguish between the major sources of variation.
- When doing a nested study, the order of the sampling plan should be maintained to preserve the hierarchy.

2. **Take data *in the order of production* (not randomly).**

   - Continue to collect data until 80% of the typical range of the response variable is observed (low to high). (This range may be estimated from historical data.)

   Note: For fully crossed designs, a Multi-Vari study can be used to graphically look at interactions with factors that are not time dependent (in which case, runs can be randomized as in a design of experiments).

3. **Take a representative sample.**

   - It is suggested that a minimum of three samples per lowest level subgroup be taken.

4. **Plot the data.**

   - The y axis will represent the scaled response variable.

- Plot the positional component on a vertical line from low to high and plot the mean for each line (each piece). (**Note**: Offsetting the bar at a slight angle from vertical can improve clarity.)
- Repeat for each positional component on neighboring bars.
- Connect the positional means of each bar to evaluate the cyclical component.
- Plot the mean of all values for each cyclical group.
- Connect cyclical means to evaluate the temporal component.
- Compare components of variation for each component (largest change in y (Δy) for each component).

Tip Many computer programs will not produce charts unless the designs are balanced or have at least one data point for each combination.

Tip Each plotted point represents an average of the factor combination selected. When a different order of factors is selected, the data, while still the same, will be re-sorted. Remember, if the study is nested, the order of the hierarchy must be maintained from the top-down or bottom-up of the sampling plan.

5. **Analyze the results.**

Ask:

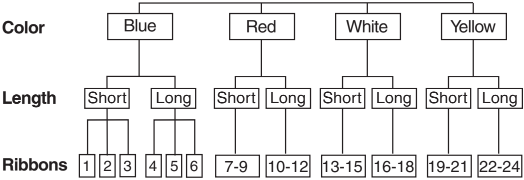
- Is there an area that shows the greatest source of variation?
- Are there cyclic or unexpected nonrandom patterns of variation?

- Are the nonrandom patterns restricted to a single sample or more?
- Are there areas of variation that can be eliminated (e.g., shift-to-shift variation)?

Example:

Several ribbons, one-half short and one-half long and in four colors (red, white, blue, and yellow), are studied. Three samples of each combination are taken, for a total of twenty-four data points (2 x 4 x 3). Ribbons are nested within the "length": ribbon one is unique to "short" and ribbon four is unique to "long." Length, however, is crossed with color: "short" is not unique to "blue." Length is repeated for all colors. (This example is a combination study, nested and crossed, as are many Gauge R&Rs.)

Multi-Vari Sampling Plan
Ribbon Example

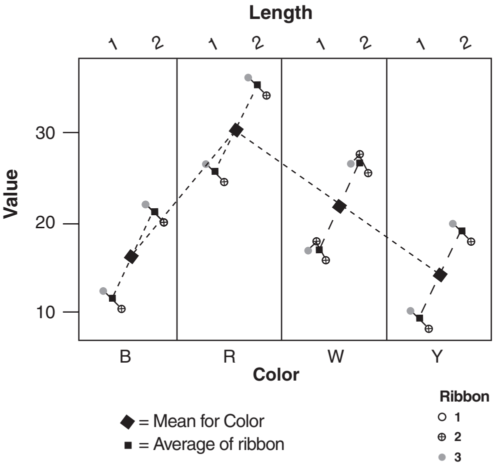


The following data set was collected. Note that there are three ribbons for each combination of length and color as identified in the "Ribbon #" column.

Color	Length	Ribbon #	Value
B	1	1	14
B	1	2	13
B	1	3	12
B	2	1	23
B	2	2	22
B	2	3	21
R	1	1	27
R	1	2	26
R	1	3	25
R	2	1	36
R	2	2	35
R	2	3	34
W	1	1	18
W	1	2	19
W	1	3	17
W	2	1	27
W	2	2	28
W	2	3	26
Y	1	1	12
Y	1	2	11
Y	1	3	10
Y	2	1	21
Y	2	2	20
Y	2	3	19

The ribbons are sorted by length, then color to get one chart.

Multi-Vari Chart for Value



- Each observation is shown by coded circles.
- The squares are averages within a given length and color.
- Each large diamond is the average of six ribbons of both lengths within a color.
- Note the obvious pattern of the first, second, and third measured ribbons within the subgroups. The short ribbons (length = 1) consistently measure low, while the long ribbons consistently measure high, and the difference between short and long ribbons (Δy) is consistent.
- There is more variation between colors than lengths (Δy is greater between colors than between lengths).

- Also note the graph indicates that while the value of a ribbon is based upon both its color and length, longer (length = 2) ribbons are in general more valuable than short ribbons. However, a short red ribbon has higher value than a long yellow one. Caution should be taken here because not much about how the individual values vary relative to this chart is known. Other tools (e.g., hypothesis tests and DOEs) are needed for that type of analysis.

Note: Because this study has nested components associated with it, extreme caution should be used before reordering the data to generate a new chart.

Central Limit Theorem

Why use it?

The Central Limit Theorem (CLT) is a foundation for parametric hypothesis testing. Understanding this theorem furthers knowledge of how to apply inferential statistics to data.

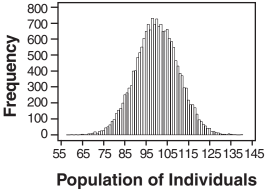
What does it do?

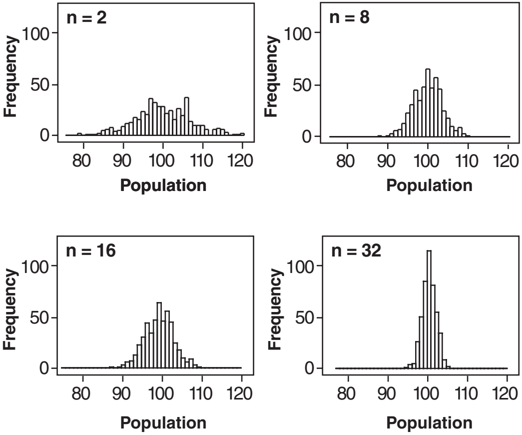
The Central Limit Theorem states that the means of random samples drawn from *any* distribution with mean μ and variance σ^2 will have an approximately normal distribution with a mean equal to μ and a variance equal to σ^2/n. The CLT allows the use of confidence intervals, hypothesis testing, DOE, regression analysis, and other analytical techniques on data.

Examples:

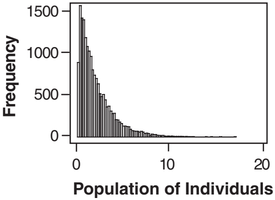
The CLT can be better understood by reviewing examples of its application. The first example takes samples from a normal distribution; the second and third examples take samples from non-normal distributions. In each case, notice how the sampling distributions are approximately normal. Also notice that as the sample size n increases, the variation decreases and the sampling distribution tends to look more like the normal distribution.

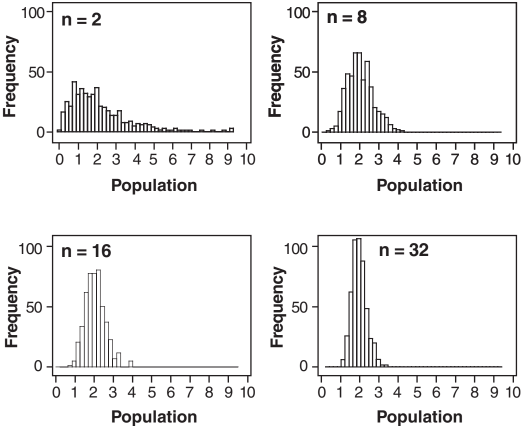
Normal Distribution



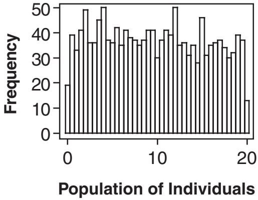


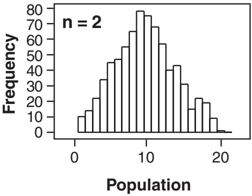
Non-normal Distribution

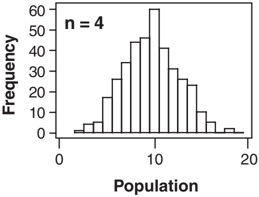




Non-normal Distribution







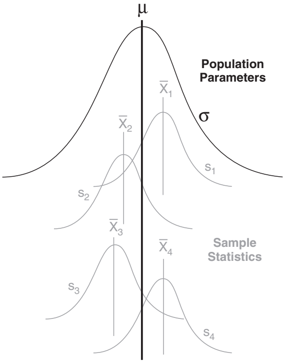
Confidence Intervals

Why use it?

Confidence intervals allow organizations to make estimates about population parameters (e.g., proportions, standard deviations, and averages) with a known degree of certainty.

What does it do?

In many processes, it is very costly and inefficient to measure every unit of product, service, or information produced. In these instances, a sampling plan is implemented and statistics such as the average, standard deviation, and proportion are calculated and used to make inferences about the population parameters. Unfortunately, when a known population is sampled many times, the calculated sample averages can be different even though the population is stable (as shown in the following figure).



Sample Averages

The differences in these sample averages are simply due to the nature of random sampling. Given that these differences exist, the key is to estimate the true population parameter. The confidence interval allows the organization to estimate the true population parameter with a known degree of certainty.

The confidence interval is bounded by a lower limit and upper limit that are determined by the risk associated with making a wrong conclusion about the parameter of interest. For example, if the 95% confidence interval is calculated for a subgroup of data of sample size n, and the lower confidence limit and the upper confidence limit are determined to be 85.2 and 89.3, respectively, it can be stated with 95% certainty that the true population average lies between these values. Conversely, there is a 5% risk (alpha (α) = 0.05) that this interval does not contain the true population average. The 95% confidence interval could also show that:

- Ninety-five of 100 subgroups collected with the same sample size n would contain the true population average.
- If another 100 subgroups were collected, ninety-five of the subgroups' averages would fall within the upper and lower confidence limits.

Note:

1. When sampling from a process, the samples are assumed to be randomly chosen and the subgroups are assumed to be independent.
2. Whether the true population average lies within the upper and lower confidence limits

that were calculated cannot be known. Thus, (1-confidence interval) equals the alpha risk (α), which is the risk that it does not. For a 95% confidence interval, the α risk is always 5%.

How do I do it?

Depending on the population parameter of interest, the sample statistics that are used to calculate the confidence interval subscribe to different distributions. Aspects of these distributions are used in the calculation of the confidence intervals. Listed below are the different confidence intervals, the distribution the sample statistics subscribe to, the formulas to calculate the intervals, and an example of each. Notice how these confidence intervals are affected by the sample size, n. Larger sample sizes result in tighter confidence intervals, as expected from the Central Limit Theorem.

Confidence Interval for the Mean

The confidence interval for the mean utilizes a t-distribution and can be calculated using the following formula:

$$\bar{X} - t_{\alpha/2}\left(\frac{s}{\sqrt{n}}\right) \le \mu \le \bar{X} + t_{\alpha/2}\left(\frac{s}{\sqrt{n}}\right)$$

Example:

A manufacturer of inserts for an automotive engine application was interested in knowing, with 90% certainty, the average strength of the inserts currently being manufactured. A sample of twenty inserts was selected and tested on a tensile tester. The average strength and standard deviation of these samples were determined to be 167,950 and 3,590 psi, respectively. The confidence interval for the mean μ would be:

$$\bar{X} - t_{\alpha/2}\left(\frac{s}{\sqrt{n}}\right) \le \mu \le \bar{X} + t_{\alpha/2}\left(\frac{s}{\sqrt{n}}\right)$$

$$167{,}950 - 1.73\left(\frac{3{,}590}{\sqrt{20}}\right) \le \mu \le 167{,}950 + 1.73\left(\frac{3{,}590}{\sqrt{20}}\right)$$

$$167{,}950 - 1{,}389 \le \mu \le 167{,}950 + 1{,}389$$

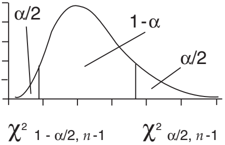
$$166{,}561 \le \mu \le 169{,}339$$

Confidence Interval for the Standard Deviation

The confidence interval for the standard deviation subscribes to a chi-square distribution and can be calculated as follows:

$$s\sqrt{\frac{(n-1)}{\chi^2_{\alpha/2,\,n-1}}} \le \sigma \le s\sqrt{\frac{(n-1)}{\chi^2_{1-\alpha/2,\,n-1}}}$$

A χ^2 Distribution



s = standard deviation of a sample
χ^2 = statistical distribution
(values are listed in a statistical table)

Example:

A manufacturer of nylon fiber is interested in knowing, with 95% certainty, the amount of variability in the tenacity (a measure of strength) of a specific yarn fiber they are producing. A sample of fourteen tubes of yarn was collected, and the average tenacity and standard deviation were determined to be 2.830 and 0.341 g/denier, respectively. To calculate the 95% confidence interval for the standard deviation:

$$s\sqrt{\frac{(n-1)}{\chi^2_{\alpha/2,\,n-1}}} \le \sigma \le s\sqrt{\frac{(n-1)}{\chi^2_{1-\alpha/2,\,n-1}}}$$

$$0.341\sqrt{\frac{(14-1)}{24.74}} \le \sigma \le 0.341\sqrt{\frac{(14-1)}{5.01}}$$

$$0.247 \le \sigma \le 0.549$$

Caution: Some software and texts will reverse the direction of reading the table; therefore, $\chi^2_{\alpha/2,\,n-1}$ would be 5.01, not 24.74.

Confidence Interval for the Proportion Defective

The exact solution for proportion defective (p) utilizes the binomial distribution; however, in this example the normal approximation will be used. The normal approximation to the binomial may be used when np and n(1-p) are greater than or equal to five. A statistical software package will use the binomial distribution.

$$p\text{-}Z_{\alpha/2}\sqrt{\frac{p\,(1-p)}{n}} \le P \le p+Z_{\alpha/2}\sqrt{\frac{p\,(1-p)}{n}}$$

(This formula is best used when np and n(1-p) > 5.)

Example:

A financial company has been receiving customer phone calls indicating that their month-end financial statements are incorrect. The company would like to know, with 95% certainty, the current proportion defective for these statements. Twelve-hundred statements were sampled and fourteen of these were deemed to be defective. The 95% confidence interval for the proportion defective would be:

$$p\text{-}Z_{\alpha/2}\sqrt{\frac{p\,(1-p)}{n}} \le P \le p+Z_{\alpha/2}\sqrt{\frac{p\,(1-p)}{n}}$$

$$0.012\text{-}1.96\sqrt{\frac{0.012(1\text{-}0.012)}{1200}} \le P \le 0.012+1.96\sqrt{\frac{0.012(1\text{-}0.012)}{1200}}$$

$$0.012\text{-}0.006 \le P \le 0.012+0.006$$

$$0.006 \le P \le 0.018$$

$$0.60\% \le P \le 1.80\%$$

Note:np = 1200 (0.12) = 14.4, which is > 5 and n(1-p) = 1200 (.988) = 1185.6, which is > 5 so the normal approximation to the binomial may be used.

Hypothesis Testing

Why use it?

Hypothesis testing helps an organization:

- Determine whether making a change to a process input (x) significantly changes the output (y) of the process.
- Statistically determine if there are differences between two or more process outputs.

What does it do?

Hypothesis testing assists in using sample data to make decisions about population parameters such as averages, standard deviations, and proportions.

Testing a hypothesis using statistical methods is equivalent to making an educated guess based on the probabilities associated with being correct. When an organization makes a decision based on a statistical test of a hypothesis, it can never know for sure whether the decision is right or wrong, because of sampling variation. Regardless how many times the same population is sampled, it will never result in the same sample mean, sample standard deviation, or sample proportion. The real question is whether the differences observed are the result of changes in the population, or the result of sampling variation. Statistical tests are used because they have been designed to minimize the number of times an organization can make the wrong decision.

There are two basic types of errors that can be made in a statistical test of a hypothesis:

1. A conclusion that the population has changed when in fact it has not.

2. A conclusion that the population has not changed when in fact it has.

The first error is referred to as a type I error. The second error is referred to as a type II error. The probability associated with making a type I error is called alpha (α) or the α risk. The probability of making a type II error is called beta (β) or the β risk.

If the α risk is 0.05, any determination from a statistical test that the population has changed runs a 5% risk that it really has not changed. There is a 1 - α, or 0.95, confidence that the right decision was made in stating that the population has changed.

If the β risk is 0.10, any determination from a statistical test that there is no change in the population runs a 10% risk that there really may have been a change. There would be a 1 - β, or 0.90, "power of the test," which is the ability of the test to detect a change in the population.

A 5% α risk and a 10% β risk are typical thresholds for the risk one should be willing to take when making decisions utilizing statistical tests. Based upon the consequence of making a wrong decision, it is up to the Black Belt to determine the risk he or she wants to establish for any given test, in particular the α risk. β risk, on the other hand, is usually determined by the following:

- δ: The difference the organization wants to detect between the two population parameters. Holding all other factors constant, as the δ increases, the β decreases.
- σ: The average (pooled) standard deviation of the two populations. Holding all other factors constant, as the σ decreases, the β decreases.

- n: The number of samples in each data set. Holding all other factors constant, as the n increases, the β decreases.
- α: The alpha risk or decision criteria. Holding all other factors constant, as the α decreases, the β increases.

Most statistical software packages will have programs that help determine the proper sample size, n, to detect a specific δ, given a certain σ and defined α and β risks.

p-Value

How does an organization know if a new population parameter is different from an old population parameter? Conceptually, all hypothesis tests are the same in that a signal (δ)-to-noise (σ) ratio is calculated (δ/σ) based on the before and after data. This ratio is converted into a probability, called the p-value, which is compared to the decision criteria, the α risk. Comparing the p-value (which is the actual α of the test) to the decision criteria (the stated α risk) will help determine whether to state the system has or has not changed.

Unfortunately, a decision in a hypothesis can never conclusively be defined as a correct decision. All the hypothesis test can do is minimize the risk of making a wrong decision.

How do I do it?

A Black Belt conducting a hypothesis test is analogous to a prosecuting attorney trying a case in a court of law. The objective of the prosecuting attorney is to collect and present enough evidence to prove beyond a reasonable doubt that a defendant is guilty. If the attorney has not done so, then the jury will assume that not enough evidence has been presented to prove guilt; therefore, they will conclude the defendant is not guilty.

A Black Belt has the same objective. If the Black Belt wants to make a change to an input (x) in an existing process to determine a specified improvement in the output (y), he or she will need to collect data after the change in x to demonstrate beyond some criteria (the α risk) that the specified improvement in y was achieved.

Note: The following steps describe how to conduct a hypothesis test for a difference in means. However, these steps are the same for any hypothesis test on any other population parameter that a Black Belt may conduct.

1. **Define the problem or issue to be studied.**
2. **Define the objective.**
3. **State the null hypothesis, identified as H_0.**
   - The null hypothesis is a statement of no difference between the before and after states (similar to a defendant being not guilty in court).

$$H_0: \mu_{before} = \mu_{after}$$

The goal of the test is to either reject or not reject H_0.

4. **State the alternative hypothesis, identified as H_a.**
   - The alternative hypothesis is what the Black Belt is trying to prove and can be one of the following:
     - $H_a: \mu_{before} \quad \mu_{after}$ (a two-sided test)
     - $H_a: \mu_{before} < \mu_{after}$ (a one-sided test)
     - $H_a: \mu_{before} > \mu_{after}$ (a one-sided test)
   - The alternative chosen depends on what the Black Belt is trying to prove. In a two-sided test, it is important to detect differences from the hypothesized mean, μ_{before}, that lie on either side of μ_{before}. The α risk in a two-sided test is split on both sides of the histogram. In a one-sided test, it is only important to detect a difference on one side or the other.

5. **Determine the practical difference (δ).**
   - The practical difference is the meaningful difference the hypothesis test should detect.
6. **Establish the α and β risks for the test.**
7. **Determine the number of samples needed to obtain the desired β risk.**
   - Remember that the power of the test is (1-β).
8. **Collect the samples and conduct the test to determine a p-value.**
   - Use a software package to analyze the data and determine a p-value.
9. **Compare the p-value to the decision criteria (α risk) and determine whether to reject H_0 in favor of H_a, or not to reject H_0.**
   - If the p-value is less than the α risk, then reject H_0 in favor H_a.
   - If the p-value is greater than the α risk, there is not enough evidence to reject H_0.

The risks associated with making an incorrect decision are described in the following table.

Decision Table

		If the decision is:	
		H_0	H_a
If the correct answer is:	H_0	*Right Decision*	**α Risk** **Type I Error**
	H_a	**β Risk** **Type II Error**	*Right Decision*

Depending on the population parameter of interest there are different types of hypothesis tests; these types are described in the following table.

Note: The table is divided into two sections: parametric and non-parametric. Parametric tests are used when the underlying distribution of the data is known or can be assumed (e.g., the data used for t-testing should subscribe to the normal distribution). Non-parametric tests are used when there is no assumption of a specific underlying distribution of the data.

Different Hypothesis Tests

	Hypothesis Test	Underlying Distribution	Purpose
Parametric (Assumes the data subscribes to a distribution)	1 Sample t-Test	Normal	Compares one sample average to a historical average or target
	2 Sample t-Test	Normal	Compares two independent sample averages
	Paired t-Test	Normal	Compares two dependent sample averages
	Test for Equal Variances	Chi-square	Compares two or more independent sample variances or standard deviations
	1 Proportion Test	Binomial	Compares one sample proportion (percentage) to a historical average or target
	2 Proportion Test	Binomial	Compares two independent proportions
	Chi-square Goodness of Fit	Chi-square	Determines whether a data set fits a known distribution
	Chi-square Test for Independence	Chi-square	Determines whether probabilities classified for one variable are associated with the classification of a second
Non-Parametric (Makes no assumption about the underlying distribution of the data)	1 Sample Sign Test	None	Compares one sample median to a historical median or target
	Mann-Whitney Test	None	Compares two independent sample medians

2 Sample t-Test Example:

A Black Belt is interested in determining whether temperature has an impact on the yield of a process. The current process runs at 100°C and results in a nominal yield of 28 kg. The Black Belt would like to change the temperature to 110°C with the hope of detecting a 3-kg increase in output. The null hypothesis is defined as:

$$H_0\!: \mu_{100°C} \quad \mu_{110°C} \text{ (one sided)}$$

and the alternative hypothesis is chosen as:

$$H_a\!: \mu_{100°C} < \mu_{110°C} \text{ (one sided)}$$

The practical difference the Black Belt would like to detect is 3 kg (an increase to 31 kg). The test is conducted with an α and β risk of 5% and 10%, respectively. To achieve a β risk of 10%, twenty-one samples will need to be collected at both 100°C and 110°C; therefore, twenty-one samples were collected at 100°C, the process temperature was changed to 110°C, and twenty-one more samples were collected. The respective averages and standard deviations were 28.2 and 3.2, and 32.4 and 3.2. The data was entered into a software program and the p-value was determined to be 0.01. After comparing the p-value (0.01) to the α risk (0.05), H_0 is rejected in favor of H_a as there is only a 1% risk in deciding H_a is greater than H_0 when compared to the initial 5% risk the Black Belt was willing to take.

2 Proportion Test Example:

A Black Belt is interested in determining whether a new method of processing forms will result in fewer defective forms. The old method resulted in 5.2% defectives. The Black Belt would like to change to a new method with the hope of reducing the percent defectives to 2.0%. The null hypothesis is defined as:

$$H_0\text{: } P_{\text{old method}} \quad P_{\text{new method}}$$

and the alternative hypothesis is chosen as:

$$H_a\text{: } P_{\text{old method}} > P_{\text{new method}}$$

The practical difference the Black Belt would like to detect is a 3.2% reduction. The test will be conducted with an α and β risk of 5% and 10%, respectively. To achieve a β risk of 10%, 579 forms will need to be collected at the old and new methods; therefore, 579 samples were collected at the old process, the new method was implemented, and 579 more samples were collected. The respective percentages were 5.2% (thirty defectives) and 2.9% (seventeen defectives). The data was entered into a software program and the p-value was determined to be 0.026. Comparing the p-value (0.026) to the α risk (0.05) results in a conclusion that H_0 should be rejected.

Transforming Data

Why use it?

Many graphical and statistical analysis tools assume the distribution of data or residuals is normal and of equal variance over the range of the analysis. If the distribution is non-normal, then the analysis may be misleading or incorrect due to the violation of the normality and equal variance assumptions. A transformation function can often be used to convert the data closer to a normal distribution to meet the assumptions and allow for a determination of statistical significance. Transformation use may be indicated by non-random patterns in the residuals of a regression, ANOVA, or DOE analysis.

What does it do?

A transformation function converts a non-normal distribution to a normal distribution. Caution must be used by the analyst in interpreting transformed data that has no physical significance.

How do I do it?

Before transforming data, it is important to see if the sample size of data is large enough to determine normality (typically thirty samples) and if the sample is representative of the process being measured. It is also important to ensure that multiple populations are not included in the sample (multiple modes or outliers may be indicative of this). Finally, the process being measured must be considered; a normal distribution profile would be characterized by data that are just as likely to be below the mean as above the mean, and that are more likely to be close to the mean than farther away from the mean.

Once it has been determined that the data or residuals are non-normal, a transformation function is used to transform the data. The same test for normality should then be performed on the transformed data. If the new distribution is normal, then an analysis that assumes normality can be used on the transformed data. If the new distribution is not normal, then the data can be transformed using a different type of transformation, or the data should be reviewed to determine if more than one population is represented or a non-parametric analysis can be conducted.

Data Transformation Types

It is often difficult to determine which transformation function to use for the data given. Many people decide which function to use by trial and error, using the standard transformation functions shown on the next page. For each function or combination of functions, the transformed data can be checked for normality using the Anderson-Darling test for normality.

A transformation function can incorporate any one or combination of the following equations, or may use additional ones not listed.

Standard Transformation Functions

- Square Root: $\sqrt{x}$
- Logarithmic: log10 *x*, ln*x*, etc.
- Reciprocal of data: $1/x$
- Square of data: x^2

There is also benefit in transforming specific distributions such as count data. This type of data often has a nonconstant variance (Poisson distribution). Recommended transformations are listed below:

- Square Root: $\sqrt{c}$
- Freeman-Tukey modification to the square root:

$$\left[\sqrt{c}+\sqrt{c+1}\right]/2$$

Another frequently encountered situation requiring transformation occurs when dealing with attribute data. Recommended transformations include:

- Arcsin $\sqrt{p}$
- Freeman-Tukey modification to arcsin:

$$\left[\arcsin\sqrt{\frac{np}{n+1}}+\arcsin\sqrt{\frac{np+1}{n+1}}\right]/2$$

By knowing the physics behind a process, the Black Belt can determine the appropriate function that describes the process. This function can be used to transform the data.

Once the transformation function is found for a given set of data, it can be used for additional data collected from the same process. Once a process has been modified, however, the distribution may change and become normal or a different type of non-normal distribution. A new transformation function may then be needed.

If choosing a transformation is difficult, many software programs will perform a Box-Cox transformation on the data. Some common Box-Cox transformations are listed in the following table.

Box-Cox Transformations

Use y^{λ} when $\lambda \neq 0$ and ln(y) when $\lambda = 0$.

If the lambda value is:	**Then the transformation value will be:**
2	y^2
0.05	$y^{0.05}$
0	ln (y)
-0.5	$1/y^{0.5}$
-1	1/y
1	No transformation required

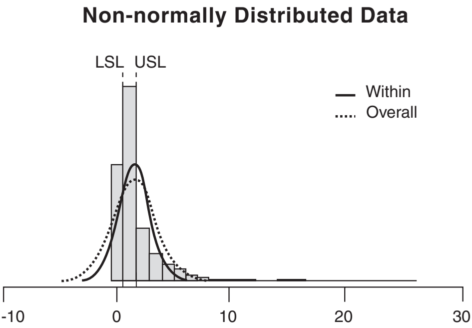
The table can be used to assess the appropriateness of the transformation. For example, the 95% confidence interval for lambda can be used to determine whether the optimum lambda value is “close” to 1, because a lambda of 1 indicates that a transformation should not be done. If the optimum lambda is close to 1, very little would be gained by performing the transformation.

As another example, if the optimum lambda is “close” to 0.5, the square root of the data could simply be calculated, because this transformation is simple and understandable.

Note: In some cases, one of the closely competing values of lambda may end up having a slightly smaller standard deviation than the estimate chosen.

Example:

A data set was evaluated and discovered to be non-normally distributed. The distribution was positively skewed because the exaggerated tail was in the positive direction.



Process Data	
USL	1.50000
Target	*
LSL	0.50000
Mean	1.62833
Sample N	500
StDev (Within)	1.56770
StDev (Overall)	2.18672

Potential (Within) Capability	
C_p	0.11
C_{pu}	-0.03
C_{pl}	0.24
C_{pk}	-0.03
C_{pm}	*

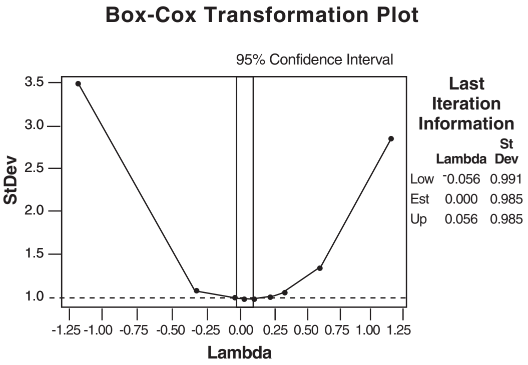
Overall Capability	
P_p	0.08
P_{pu}	-0.02
P_{pl}	0.17
P_{pk}	-0.02

Observed Performance	
P_{pm}<LSL	260000.00
P_{pm}>USL	300000.00
P_{pm} Total	560000.00

Exp. "Within" Performance	
P_{pm}<LSL	235844.41
P_{pm}>USL	532619.36
P_{pm} Total	768463.77

Exp. "Overall" Performance	
P_{pm}<LSL	302930.55
P_{pm}>USL	523398.10
P_{pm} Total	826328.65

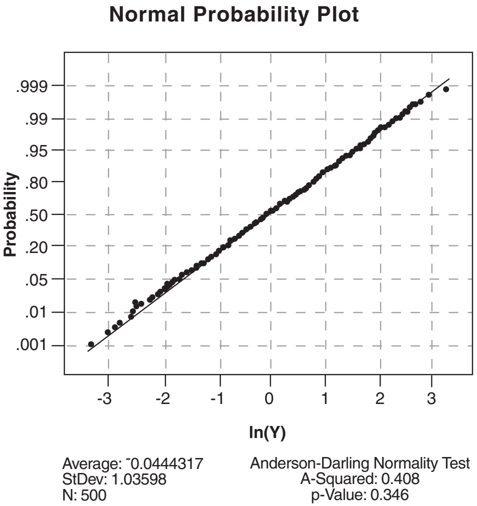
The same data set was evaluated using a Box-Cox transformation analysis. The Box-Cox transformation plot is shown below.



	Lambda	St Dev
Low	-0.056	0.991
Est	0.000	0.985
Up	0.056	0.985

In this example, the best estimate for lambda is zero or the natural log. (In any practical situation, the Black Belt would want a lambda value that corresponds to an understandable transformation, such as the square root (a lambda of 0.5) or the natural log (a lambda of 0).) Zero is a reasonable choice because it falls within the 95% confidence interval and happens to be the "best" estimate of lambda. Therefore, the natural log transformation will be used.

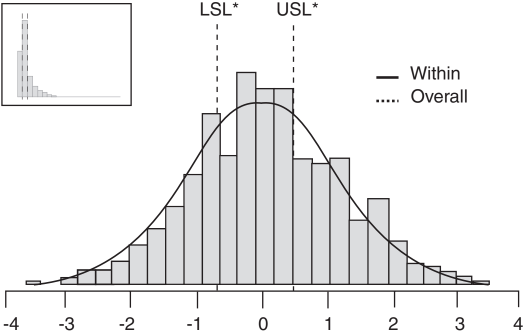
After performing the recommended transformation on the data set, a test for normality was done to validate the transformation. (The normal probability plot for this data is shown on the next page.)



The normal probability plot of the transformed data can be graphically interpreted by the fit of the data to a straight line, or analytically interpreted from the results of the Anderson-Darling test for normality. The p-value (0.346) is greater than the α risk we are willing to take, indicating that there is sufficient evidence that the transformed distribution is normally distributed.

The original lognormal capability data has been transformed into the normal distribution shown on the next page. (The * in the graphic indicates transformed data. For example, the actual USL is 1.50; however, the transformed USL is 0.405.)

Transformed Capability Data



Process Data

USL	1.50000
USL*	0.40547
Target	*
Target*	*
LSL	0.50000
LSL*	-0.69315
Mean	1.62833
Mean*	-0.04443
Sample N	500
StDev (Within)	1.56770
StDev* (Within)	1.02145
StDev (Overall)	2.18672
StDev* (Overall)	1.03650

Potential (Within) Capability

C_p	0.18
C_{pu}	0.15
C_{pl}	0.21
C_{pk}	0.15
C_{pm}	*

Overall Capability

P_p	0.18
P_{pu}	0.14
P_{pl}	0.21
P_{pk}	0.14

Observed Performance

P_{pm}<LSL	260000.00
P_{pm}>USL	300000.00
P_{pm} Total	560000.00

Exp. "Within" Performance

P_{pm}<LSL*	262683.84
P_{pm}>USL*	329805.84
P_{pm} Total	592489.68

Exp. "Overall" Performance

P_{pm}<LSL*	265699.92
P_{pm}>USL*	332124.86
P_{pm} Total	597824.78

The potential and overall capabilities are now more accurate for the process at hand. The use of non-normal data may result in an erroneous calculation of predicted proportion out of the specified units. When transforming capability data, remember that any specification limit must also be transformed. (Most software packages will perform this automatically.)

Notice from a comparison of the before and after capability outputs that we are only slightly more capable than our original estimate with the lognormal data. There is excessive variation in the process. The primary focus of the Black Belt should be to identify and correct the sources of this variation.

Correlation and Regression

Correlation

Why use it?

Correlation is used to determine the strength of linear relationships between two process variables. It allows the comparison of an input to an output, two inputs against each other, or two outputs against each other.

What does it do?

Correlation measures the degree of association between two independent continuous variables. However, even if there is a high degree of correlation, this tool does not establish causation. For example, the number of skiing accidents in Colorado is highly correlated with sales of warm clothing, but buying warm clothes did not cause the accidents.

How do I do it?

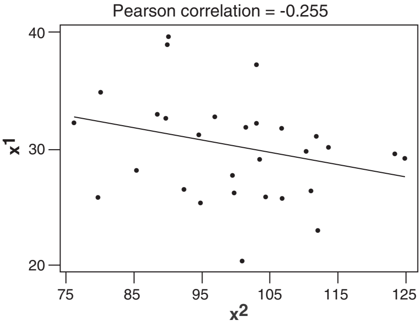
Correlation can be analyzed by calculating the Pearson product moment correlation coefficient (r). This coefficient is calculated as follows:

$$r_{xy} = \frac{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{X})(y_i - \bar{y})}{S_x S_y}$$

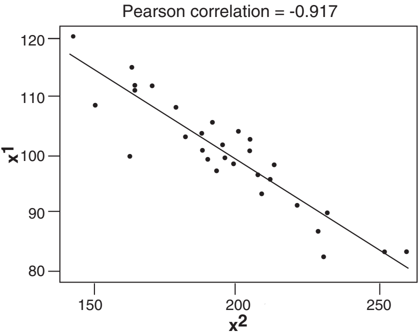
Where S_x and S_y are the sample standard deviations.

The resulting value will be a number between -1 and +1. The higher the absolute value of r, the stronger the correlation. A value of zero means there is no correlation. A strong correlation is characterized by a tight distribution of plotted pairs about a best-fit line. It should be noted that correlation does not measure the slope of the best-fit line; it measures how close the data are to the best-fit line. A negative r implies that as one variable (x^2) increases, the other variable (x^1) decreases.

Weak Negative Correlation

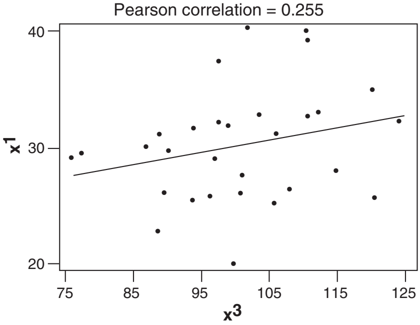


Strong Negative Correlation

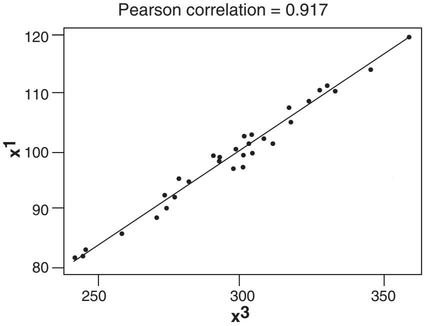


A positive r implies that as one variable (x^3) increases, the other variable (x^1) also increases.

Weak Positive Correlation

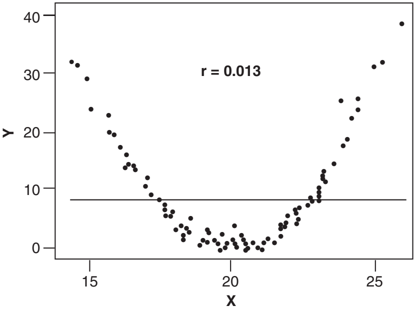


Strong Positive Correlation



As stated earlier, correlation is a measure of the linear relationship between two variables. A strong relationship other than linear can exist, yet r can be close to zero.

Strong Non-Linear Relationship



Regression

Why use it?

Regression measures the strength of association between independent factor(s) (also called predictor variable(s) or regressors) and a dependent variable (also called a response variable). For simple or multiple linear regression, the dependent variable must be a continuous variable. Predictor variables can be continuous or discrete, but must be independent of one another. Discrete variables may be coded, discrete levels (dummy variables (0, 1) or effects coding (-1, +1)).

- *Simple linear regression* relates a single x to a y. It has a single regressor (x) variable and its model is linear with respect to coefficients (a).

  Examples:

$$y = a_0 + a_1x + \text{error}$$

$$y = a_0 + a_1x + a_2 x^2 + a_3 x^3 + \text{error}$$

Note: "Linear" refers to the coefficients a_0, a_1, a_2, etc. In the second example, the relationship between x and y is a cubic polynomial in nature, but the model is still linear with respect to the coefficients.

- *Multiple linear regression* relates multiple x's to a y. It has multiple regressor (x) variables such as x_1, x_2, and x_3. Its model is linear with respect to coefficients (b).

  Example:

  $$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + \text{error}$$

- *Binary logistic regression* relates x's to a y that can only have a dichotomous (one of two mutually exclusive outcomes such as pass/fail, on/off, etc.) value. (For more information on this subject, see the binary logistic regression chapter in this book.)
- Other regression equations such as nonlinear regressions are possible but are beyond the scope of this book and are best performed by computer programs. Other logistic regressions (which use discrete data) such as ordinal (three or more categories of natural order such as mild, medium, and hot) or nominal (three or more categories of no natural order such as yellow, blue, and red) are also possible but are similarly beyond the scope of this book.

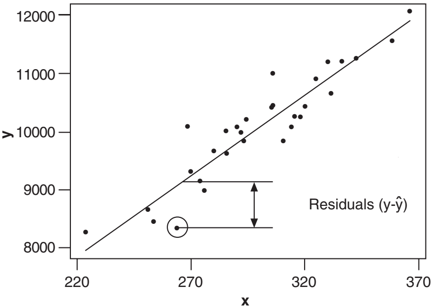
How do I do simple regression?

1. **Determine which relationship will be studied.**
2. **Collect data on the x and y variables.**
3. **Set up a fitted line plot by charting the independent variable on the x axis and the dependent variable on the y axis.**
4. **Create the fitted line.**
   - If creating the fitted line plot by hand, draw a straight line through the values that keep the least

amount of total space between the line and the individual plotted points (a "best fit").

- If using a computer program, compute and plot this line via the "least squares method."

Fitted Line Plot



5. **Compute the correlation coefficient r, using the equation defined earlier in this chapter.**
6. **Determine the slope or y intercept of the line by using the equation y = mx + b.**
    - The y intercept (b) is the point on the y axis through which the "best fitted line" passes (at this point, x = 0).
    - The slope of the line (m) is computed as the change in y divided by the change in x ($m = \Delta y/\Delta x$). The slope, m, is also known as the coefficient of the predictor variable, x.
7. **Calculate the residuals.**
    - The difference between the predicted response variable (called the fits, $\hat{y}$) for any given x and the experimental value or actual response (y) is called the residual ($e = y - \hat{y}$). The residual is used

to determine if the model is a good one to use. The estimated standard deviation of the residuals is a measure of the error term about the regression line.

8. **To determine significance, perform a t-test (with the help of a computer) and calculate a p-value for each factor.**
   - A p-value less than α (usually 0.05) will indicate a statistically significant relationship.
9. **Analyze the entire model for significance using ANOVA, which displays the results of an F-test with an associated p-value.**
10. **Calculate R^2 and R^2_{adj}.**
    - R^2, the coefficient of determination, is the square of the correlation coefficient and measures the proportion of variation that is explained by the model. Ideally, R^2 should be equal to one, which would indicate zero error.

$$\begin{aligned} R^2 &= SS_{regression} / SS_{total} \\ &= (SS_{total} - SS_{error}) / SS_{total} \\ &= 1-[SS_{error} / SS_{total}] \end{aligned}$$

Where SS = the sum of the squares.

- R^2_{adj} is a modified measure of R^2 that takes into account the number of terms in the model and the number of data points.

$$R^2_{adj} = 1- [SS_{error} / (n-p)] / [SS_{total} / (n-1)]$$

Where n = number of data points and p = number of terms in the model. The number of terms in the model also includes the constant.

Note: Unlike R^2, R^2_{adj} can become smaller when added terms provide little new information and as the number of model terms gets closer to the total sample size. Ideally, R^2_{adj} should be maximized and as close to R^2 as possible.

Conclusions should be validated, especially when historical data has been used.

Example:

A Black Belt wants to determine if there is a relationship between the amount of shelf space allocated for a specific product and the sales volume for that same product. She investigates thirty different stores of the same chain, all with similar demographics. Data is collected comparing shelf space allocated (x) to sales (y). Using a computer program to run an ANOVA shows the following result:

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	23.3107	23.3107	181.234	0.000
Error	28	3.6014	0.1286		
Total	29	26.9121	s = 0.3586, n = 30, & # of terms, p = 2		

$R^2 = SS_{regression}/SS_{total} = 23.3107 / 26.9121 = 86.6\%$

Note: Square the correlation coefficient (r) and compare.

86.6% of variation in sales can be attributed to shelf space.

$$R^2_{adj} = 1- [SS_{error} / (n-p)] / [SS_{total}/ (n-1)]$$
$$= 1- [3.6014 / (30 – 2)] / [26.9121 / (30 – 1)]$$
$$= 1- 0.1286 / 0.9280 = 86.1\%$$

DF = Degrees of freedom
SS = Sum of squares
MS = Mean square
F = F ratio
s = Standard deviation
P = p-value

Correlation analysis shows a strong positive correlation (r = +0.931).

Strong Positive Correlation Between Shelf Space and Sales

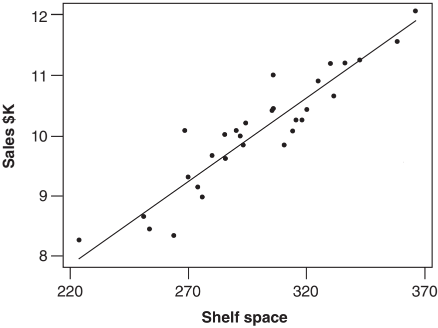
b = 1.7712 and m = 0.0276, which implies that for each unit of shelf space, sales increase $27.60.

Sales $K = 1.77121 + 0.0276075 shelf space

Correlation, $r = +0.931$

$R^2 = 86.6\%$

$R^2_{adj} = 86.1\%$



How do I do more advanced techniques such as multiple regression and residual analysis?

Using a computer program, a similar method is used in performing multiple regression, but the x axis can no longer represent a single factor.

1. **After obtaining a prediction equation (y = mx + b), analyze the residuals to validate the assumptions for regression.**

   Residuals should:

   - Be normally distributed with a mean of zero.

- Show no pattern (i.e., be random).
- Have constant variance when plotted against any regression factor or predicted values/fits.
- Be independent of the predictor variables (x's).
- Be independent of each other.

2. **Check for patterns.**
   - Any significant pattern seen may be an indication of a missed factor. Add extra factors, try a quadratic multiplier, or modify the formula or transform the data and reanalyze the model.
3. **Once any patterns are eliminated, confirm that multicolinearity is minimized.**
   - Multicolinearity is a measure of correlation between the dependent variables and can be quantified with the Variation Inflation Factor. (Ideally, VIF < 5.) (More detail about VIF goes beyond the scope of this book. For detailed information, see *Introduction to Linear Regression Analysis* by D.C. Montgomery and E.A. Peck.)
4. **Calculate R^2 and R^2_{adj}.**

   Tip Make sure that the R^2_{adj} is the highest value obtainable with the fewest (simplest model) number of variables. Best subsets and stepwise regression are methodologies that help this optimizing effort.

Example:

A Black Belt wants to evaluate the effect of three continuous factors (temperature, pressure, and dwell) on the yield of a process.

Data from twenty-one runs is collected and, as shown in the table below, all three factors are statistically significant, giving a regression formula of four terms ($n = 21$ and $p = 4$). This computer-generated output provides the ANOVA table and p-values, confirming the validity of our model (F-test) and its component factors (t-tests).

ANOVA and p-Values

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	2572.87	857.62	52.81	0.000
Residual Error	17	276.08	16.24		
Total	20	2848.95			

Predictor	Coef	SE Coef	T	P
Constant	-25.402	9.761	-2.60	0.019
Temp	0.13519	0.04735	2.86	0.011
Pressure	0.33252	0.08038	4.14	0.001
Dwell	0.11444	0.05319	2.15	0.046

Note: All three factors are significant because they are less than the α risk (0.05) we are willing to take.

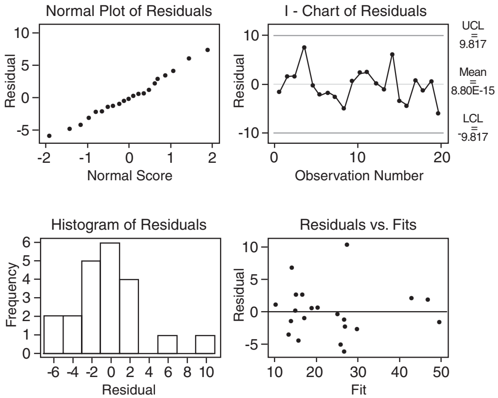
Yield = -25.4 + 0.135 Temp + 0.333 Pressure + 0.114 Dwell

$$R^2 = SS_{regression}/SS_{total} = 2572.87 / 2848.95 = 90.3\%$$

$$\begin{aligned} R^2_{adj} &= 1- [SS_{error} / (n-p)] / [SS_{total} / (n-1)] \\ &= 1- [276.08 / (21 - 4)] / [2848.95 / (21 - 1)] \\ &= 1- 16.24 / 142.45 = 88.6\% \end{aligned}$$

The residuals were analyzed to validate the assumptions for regression/ANOVA.

Residuals Analysis



Some computer programs will scan the residuals and identify any standardized residual over a set limit (typically two). This is essentially an identification of potential outliers possibly worth investigating.

Standardized Residual = Residual ÷ Standard Deviation of the Residual.

Binary Logistic Regression

Why use it?

Binary logistic regression (BLR) is used to establish a $y = f(x)$ relationship when the dependent variable (y) is binomial or dichotomous. Similar to regression, it explores the relationships between one or more predictor variables and a binary response. BLR enables the Black Belt to predict the probability of future events belonging to one group or another (i.e., pass/fail, profitable/non-profitable, or purchase/not purchase).

What does it do?

The predictor variables (x's) can be either continuous or discrete, just as for any problem using regression. However, the response variable has only two possible values (e.g., pass/fail, etc.). Because regression analysis requires a continuous response variable that is not bounded, this must be corrected. This is accomplished by first converting the response from events (e.g., pass/fail) to the probability of one of the events, or p. Thus if p = Probability(pass), then p can take on any value from 0 to 1. This conversion results in a continuous response, but one that is still bounded. An additional transformation is required to make the response both continuous and unbounded. This is called the link function. The most common link function is the "logit," which is explained below.

$$Y = \beta_0 + \beta_1 x$$

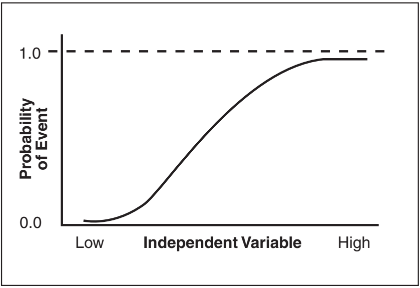
We need a continuous, unbounded Y.

$0 < p < 1 \qquad 0 < \dfrac{p}{1-p} < \infty \qquad \dfrac{p}{1-p}$ is called the "odds"

$-\infty < \ln\left(\dfrac{p}{1-p}\right) < +\infty \qquad \ln\left(\dfrac{p}{1-p}\right)$ is the "logit"

BLR fits sample data to an S-shaped logistic curve. The curve represents the probability of the event.

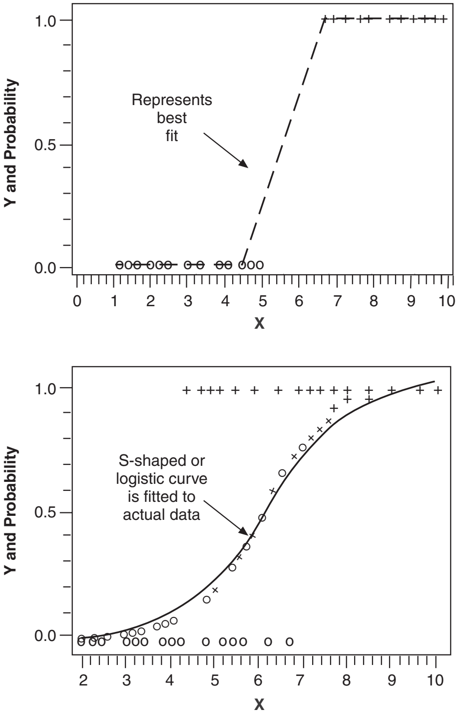
BLR Fits Data to a Probability Curve



At low levels of the independent variable (x), the probability approaches zero. As the predictor variable increases, the probability increases to a point where the slope decreases. At high levels of the independent variable, the probability approaches 1.

The following two examples fit probability curves to actual data. The curve on the top represents the "best fit." The curve through the data on the bottom contains a zone of uncertainty where events and non-events (1's and 0's) overlap.

Probability Curve Examples



If the probability of an event, p, is greater than 0.5, binary logistic regression would predict a "yes" for the event to occur. The probability of an event *not* occurring is described as (1-p). The odds, or p/(1-p), compares the probability of an event occurring to the probability of it not occurring. The logit, or "link" function, represents the relationship between x and y.

$$\ln\left(\frac{P_{\text{event}}}{P_{\text{non-event}}}\right) = \beta_0 + \beta_1 x_1 \cdots + \beta_n x_n = \ln\left(\frac{p}{1-p}\right)$$

$$P_{(\text{event})} = \frac{e^{f}}{1+e^{f}} \quad \text{where} \quad f = \beta_0 + \beta_1{}^{x}$$

How do I do it?

1. **Define the problem and the question(s) to be answered.**
2. **Collect the appropriate data in the right quantity.**
3. **Hypothesize a model.**
4. **Analyze the data.**
   - Many statistical software packages are available to help analyze data.
5. **Check the model for goodness of fit.**
6. **Check the residuals for violations of assumptions.**
7. **Modify the model, if required, and repeat.**

Interpreting the results of BLR

Most statistical software will estimate coefficients, which represent the change in the logit, or ln(p/(1-p)), corresponding to a one-unit change in an x variable, if all other x variables are held constant. Also, for each x variable, one can obtain an "odds ratio." This is the ratio of the "odds" with a particular x at some base value (x_0) compared to the "odds" if the same x variable were increased by 1 unit (i.e., $x = x_0 + 1$). The "odds ratio" for each x variable is calculated directly from the coefficient (β) for that x (i.e., it is e^β).

Positive coefficients mean that the predicted probability of the event increases as the input (x) increases. Positive coefficients also result in an odds ratio that is > 1.

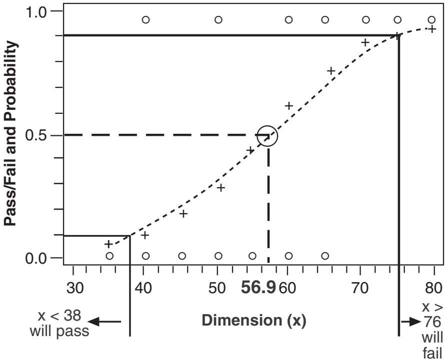
Negative coefficients mean that the predicted probability of the event decreases as the input (x) increases. Negative coefficients also result in an odds ratio that is < 1.

A coefficient of 0 means that there is no change in the predicted probability of the event as the input (x) increases. This also results in an odds ratio that is = 1. Variables with coefficients close to 0 or odds ratios close to 1 can be removed from the model.

In the following example, a value of 1.0 means the event is a "failure."

Using a Probability Curve to Predict an Event

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x \qquad X_{50} = \frac{-\beta_0}{\beta_1} = \frac{7.092}{0.12463} = 56.9$$



A dimension of 56.9 has a 50% chance of failing. As the dimension increases, it is more likely to cause a failure. Two other dimensions have also been highlighted: a dimension of 38 only has a 10% chance of failing while a dimension of 76 has a 90% probability of failure.

Design of Experiments

Why use it?

Design of experiments (DOE) is used to understand the effects of the factors and interactions that impact the output of a process. As a battery of tests, a DOE is designed to methodically build understanding and enhance the predictability of a process.

Note: There are many kinds of DOEs. This book will only consider full and fractional factorial DOEs. These DOEs emphasize the role that interactions and noise play in understanding a process. A brief overview of other DOE designs is listed at the end of this chapter.

What does it do?

A DOE investigates a list of potential factors whose variation might impact the process output. These factors can be derived from a variety of sources including process maps, FMEAs, Multi-Vari studies, Fishbone Diagrams, brainstorming techniques, and Cause and Effect Matrices.

The types of DOEs include:

- *Screening DOEs*, which ignore most of the higher order interaction effects so that the team can reduce the candidate factors down to the most important ones.
- *Characterization DOEs*, which evaluate main factors and interactions to provide a prediction equation. These equations can range from 2^k designs up to general linear models with multiple factors at multiple levels. Some software packages readily evaluate nonlinear effects using center points and also allow for the use of blocking in 2^k analyses.

- *Optimizing DOEs*, which use more complex designs such as Response Surface Methodology or iterative simple designs such as evolutionary operation or plant experimentation to determine the optimum set of factors.
- *Confirming DOEs*, where experiments are done to ensure that the prediction equation matches reality.

Understanding DOEs requires an explanation of certain concepts and terms.

- A *balanced design* will have an equal number of runs at each combination of the high and low settings for each factor.
- Two columns in a design matrix are *orthogonal* if the sum of the products of their elements within each row is equal to zero.

  Note: When a factorial experiment is balanced, the design is said to be completely orthogonal. The Pearson correlation coefficient of all of the factor and interaction columns will be zero.
- *Aliasing* (which is also referred to as confounding) occurs when the analysis of a factor or interaction cannot be unambiguously determined because the factor or interaction settings are identical to another factor or interaction, or is a linear combination of other factors or interactions. As a result, the Black Belt might not know which factor or interaction is responsible for the change in the output value. Note that aliasing / confounding can be additive, where two or more insignificant effects add and give a false impression of statistical validity. Aliasing can also offset two important effects and essentially cancel them out.
- The principle of *design projection* states that if the outcome of a fractional factorial design has insignificant terms, the insignificant terms can be

removed from the model, thereby reducing the design. For example, determining the effect of four factors for a full factorial design would normally require sixteen runs (a 2^4 design). Because of resource limitations, only a half fraction (a $2^{(4-1)}$ design) consisting of eight trials can be run. If the analysis showed that one of the main effects (and associated interactions) was insignificant, then that factor could be removed from the model and the design analyzed as a full factorial design. A half fraction has therefore become a full factorial. (**Note:** This procedure requires the experiment design to be orthogonal.)

- *Blocking* allows the team to study the effects of noise factors and remove any potential effects resulting from a known noise factor. For example, an experimental design may require a set of eight runs to be complete, but there is only enough raw material in a lot to perform four runs. There is a concern that different results may be obtained with the different lots of material. To prevent these differences, should they exist, from influencing the results of the experiment, the runs are divided into two halves with each being balanced and orthogonal. Thus, the DOE is done in two halves or "blocks" with "material lot" as the blocking factor. (Because there is not enough material to run all eight experiments with one lot, some runs will have to be done with each material anyway.) Analysis will determine if there is a statistically significant difference in these two blocks. If there is no difference, the blocks can be removed from the model and the data treated as a whole. Blocking is a way of determining which trials to run with each lot so that any effect from the different material will not influence the decisions made about the effects of the factors being explored. If the blocks are significant, then the experimenter was correct in the choice of blocking factor and the noise due to the blocking factor was minimized. This may also lead to more experimentation on the blocking factor.

- *Resolution* is the amount and structure of aliasing of factors and interactions in an experimental design. Roman numerals are used to indicate the degree of aliasing, with Resolution III being the most confounded. A full factorial design has no terms that are aliased. The numeral indicates the aliasing pattern. A Resolution III has main effects and two-way interactions confounded (1+2 = III). A Resolution V has one-way and four-way interactions as well as two-way and three-way interactions aliased (1+4 = V = 2+3).
- *Randomization* is a technique to distribute the effect of unknown noise variables over all the factors. Because some noise factors may change over time, any factors whose settings are not randomized could be confounded with these time-dependent elements. Examples of factors that change over time are tool wear, operator fatigue, process bath concentrations, and changing temperatures throughout the day.
- A *random factor* is any factor whose settings (such as any speed within an operating range) could be randomly selected, as opposed to a *fixed factor* whose settings (such as the current and proposed levels) are those of specific interest to the Black Belt. Fixed factors are used when an organization wishes to investigate the effects of particular settings or, at most, the inference space enclosed by them. Random factors are used when the organization wishes to draw conclusions about the entire population of levels.
- The *inference space* is the operating range of the factors. It is where the factor's range is used to

infer an output to a setting not used in the design. Normally, it is assumed that the settings of the factors within the minimum and maximum experimental settings are acceptable levels to use in a prediction equation. For example, if factor A has low and high settings of five and ten units, it is reasonable to make predictions when the factor is at a setting of six. However, predictions at a value of thirteen cannot and should not be attempted because this setting is outside the region that was explored. (For a 2^k design, a check for curvature should be done prior to assuming linearity between the high and low outputs.)

- A *narrow inference* utilizes a small number of test factors and/or factor levels or levels that are close together to minimize the noise in a DOE. One example of a narrow inference is having five machines, but doing a DOE on just one machine to minimize the noise variables of machines and operators.
- A *broad inference* utilizes a large number of the test factors and/or factor levels or levels that are far apart, recognizing that noise will be present. An example of a broad inference is performing a DOE on all five machines. There will be more noise, but the results more fully address the entire process.
- A *residual* is a measure of error in a model. A prediction equation estimates the output of a process at various levels within the inference space. These predicted values are called fits. The residual is the difference between a fit and an actual experimentally observed data point.
- *Residual analysis* is the graphical analysis of residuals to determine if a pattern can be detected. If the prediction equation is a good model, the residuals will be independently and normally distributed with a mean of zero and a constant variance.

Nonrandom patterns indicate that the underlying assumptions for the use of ANOVA have not been met. It is important to look for nonrandom and/or non-normal patterns in the residuals. These types of patterns can often point to potential solutions. For example, if the residuals have more than one mode, there is most likely a missing factor. If the residuals show trends or patterns vs. the run order, there is a time-linked factor.

- A DOE may use *continuous and/or discrete factors*. A continuous factor is one (such as feed rate) whose levels can vary continuously, while a discrete factor will have a predetermined finite number of levels (such as supplier A or supplier B). Continuous factors are needed when true curvature/center point analysis is desired.
- The *sparsity of effects principle* states that processes are usually driven by main effects and low-order interactions.

How do I do a DOE?

In general, the steps to perform a DOE include:

1. **Document the initial information.**
2. **Verify the measurement systems.**
3. **Determine if baseline conditions are to be included in the experiment. (This is usually desirable.)**
4. **Make sure clear responsibilities are assigned for proper data collection.**
5. **Always perform a pilot run to verify and improve data collection procedures.**
6. **Watch for and record any extraneous sources of variation.**
7. **Analyze data promptly and thoroughly.**

8. **Always run one or more verification runs to confirm results (i.e., go from a narrow to broad inference).**

How do I set up an experiment?

1. **State the practical problem.**
   - For example, a practical problem may be "Improve yield by investigating factor A and factor B. Use an α of 0.05."
2. **State the factors and levels of interest.**
   - For example, factors and levels of interest could be defined as, "Set coded values for factors A and B at -1 and +1."
3. **Select the appropriate design and sample size based on the effect to be detected.**
4. **Create an experimental data sheet with the factors in their respective columns.**
   - Randomize the experimental runs in the data sheet. Conduct the experiment and record the results.

How do I analyze data from an experiment?

5. **Construct an Analysis of Variance (ANOVA) table for the full model.**
6. **Review the ANOVA table and eliminate effects with p-values above α.**
   - *Remove these one at a time*, starting with the highest order interactions.
7. **Analyze the residual plots to ensure that the model fits.**
8. **Investigate the significant interactions (p-value < α).**
   - Assess the significance of the highest order interactions first. (For two-way interactions, an interactions plot may be used to efficiently

determine optimum settings. For graphical analysis to determine settings for three-way interactions, it is necessary to evaluate two or more interactions plots simultaneously.)

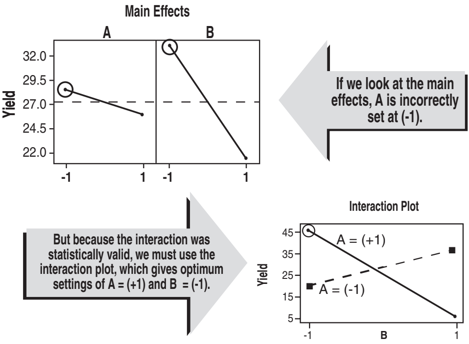
- Once the highest order interactions are interpreted, analyze the next set of lower order interactions.

9. **Investigate the significant main effects (p-value < α).**

   (**Note:** If the level of the main effect has already been set as a result of a significant interaction, this step is not needed.)

   - The use of the main effects plots is an efficient way to identify these values. Main effects that are part of statistically valid interactions must be kept in the model, regardless of whether or not they are statistically valid themselves. Care must be taken because, due to interactions, the settings chosen from a main effects plot may sometimes lead to a suboptimized solution. If there is a significant interaction, use an interaction plot, as shown in the following chart.

Main Effects and Interactions Plot



If we look at the main effects, A is incorrectly set at (-1).

But because the interaction was statistically valid, we must use the interaction plot, which gives optimum settings of A = (+1) and B = (-1).

10. State the mathematical model obtained.

- For a 2^k design, the coefficients for each factor and interaction are one-half of their respective effects. Therefore, the difference in the mean of the response from the low setting to the high setting is twice the size of the coefficients. Commonly available software programs will provide these coefficients as well as the grand mean. The prediction equation is stated, for two factors, as:

$$y = \text{grand mean} + \beta_1 X_1 + \beta_2 X_2 + \beta_3 (X_1 \times X_2)$$

11. Calculate the percent contribution of each factor and each interaction relative to the total "sum of the squares."

- This is also called *epsilon squared*. It is calculated by dividing the sum of the squares for each factor by the total sum of the squares and is a rough evaluation of "practical" significance.

12. Translate the mathematical model into process terms and formulate conclusions and recommendations.

13. Replicate optimum conditions and verify that results are in the predicted range. Plan the next experiment or institutionalize the change.

Example:

An organization decided that it wanted to improve yield by investigating the pressure and temperature in one of its processes. Coded values for pressure and temperature were set at -1 and +1. The design and sample size chosen involved two replications of a 2^2 design for a total of eight runs. The experiment was conducted and the results were recorded in the data sheet on the next page.

Run Order	Pressure	Temperature	Yield
1	-1	1	10
2	1	-1	15
3	-1	-1	23
4	1	-1	16
5	-1	-1	25
6	-1	1	9
7	1	1	8
8	1	1	6

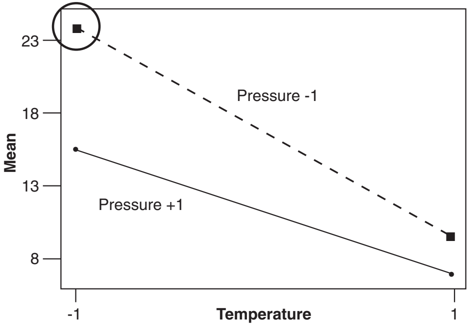
The Analysis of Variance (ANOVA) table for the full model was then constructed:

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F_0	p-Value
Pressure (P)	60.5	1	60.50	48.4	0.002
Temperature (T)	264.5	1	264.50	211.6	0.000
Interaction (P x T)	18.0	1	18.00	18.0	0.019
Error	5.0	4	1.25		
Total	348.0	7			

The ANOVA table was reviewed to eliminate the effects with a p-value above α. Because both main effects and the interaction were below the chosen α of 0.05, all three were included in the final model. The residual plots were analyzed in three ways, to ensure that the model fit: 1) The residuals were plotted against the order of the data using an Individuals Chart and Run Chart to check that they were randomly distributed about zero. 2) A normal probability plot was run on the residuals. 3) A plot of the residuals vs. the fitted or predicted values was run to check that the variances were equal (i.e., the residuals were independent of the fitted values).

Creating an interactions plot for pressure and temperature showed that the optimum setting to maximize yield was to set both temperature and pressure at -1.

Pressure/Temperature Interactions Plot



The chosen mathematical model involved the prediction equation:

$$y = \text{grand mean} + \beta_1 X_1 + \beta_2 X_2 + \beta_3 (X_1 \times X_2)$$

Substituting a grand mean of 14.00 and coefficients of -2.75 for pressure, -5.75 for temperature, and 1.50 for (P x T) into the equation, we get:

$$y = 14.00 - 2.75(\text{Pressure}) - 5.75(\text{Temperature}) + 1.5(\text{P} \times \text{T})$$

Using the optimum settings of pressure = -1 and temperature = -1 that were identified earlier forces the setting for the interaction (P x T) to be (-1) x (-1) = +1.

Substituting these values into the prediction equation, we get:

$$y = 14.00 - 2.75(-1) - 5.75(-1) + 1.5(+1) = 24.00$$

This equation tells us that, to increase yield, the pressure and temperature must be lowered. The results should be verified via confirmation runs and experiments at even lower settings of temperature and pressure should also be considered.

How do I pick factor settings?

- Process knowledge: Understand that standard operating conditions in the process could limit the range for the factors of interest. Optimum settings may be outside this range. For this reason, choose bold settings, while never forgetting safety.
- Risk: Always consider that bold settings could possibly endanger equipment or individuals and must be evaluated for such risk. Avoid settings that have the potential for harm.
- Cost: Cost is always a consideration. Time, materials, and/or resource constraints may also impact the design.
- Linearity: If there is a suspected nonlinear effect, budget for runs to explore for curvature and also make sure the inference space is large enough to detect the nonlinear effect.

Notation

The general notation to designate a fractional factorial design is:

$$2^{k-p}_{R}$$

2^{4-1}_{IV} Four factors at two levels, evaluated in eight runs. Resolution is IV.

Where:

- k is the number of factors to be investigated.
- p designates the fraction of the design.
- 2^{k-p} is the number of runs. For example, a 2^5 design requires thirty-two runs, a 2^{5-1} (or 2^4) design requires sixteen runs (a half-fractional design), and a 2^{5-2} (or 2^3) design requires eight runs (a quarter-fractional design).
- R is the resolution.

How does coding work?

Coding is the representation of the settings picked in standardized format. Coding allows for clear comparison of the effects of the chosen factors.

The design matrix for 2^k factorials is usually shown in standard order. The Yates standard order has the first factor alternate low settings, then high settings, throughout the runs. The second factor in the design alternates two runs at the low setting, followed by two runs at the high setting.

The low level of a factor is designated with a "-" or -1 and the high level is designated with a "+" or 1. An example of a design matrix for a 2^2 factorial appears on the next page.

A 2^2 and 2^3 Factorial Design Matrix

Temperature	Concentration
-1	-1
1	-1
-1	1
1	1

Adding another factor duplicates the design.

Factor	Level Low	Level High
Temperature (A)	-1	1
Concentration (B)	-1	1
Catalyst (C)	-1	1

Temperature	Concentration	Catalyst
-1	-1	-1
1	-1	-1
-1	1	-1
1	1	-1
-1	-1	1
1	-1	1
-1	1	1
1	1	1

Tip It is easy to increase the factors in a full factorial design by doubling the previous model and making the first-half settings low and the second-half settings high for the added factor.

Coded values can be analyzed using the ANOVA method and yield a $y = f(x)$ prediction equation.

Tip The prediction equation will be different for coded vs. uncoded units. However, the output range will be the same.

Even though the actual factor settings in an example might be temperature 160° and 180° C, 20% and 40% concentration, and catalysts A and B, all the settings could be analyzed using -1 and +1 settings without losing any validity.

How do I choose fractional vs. full DOEs?

There are advantages and disadvantages for all DOEs. The DOE chosen for a particular situation will depend on the conditions involved.

Advantages of full factorial DOEs:

- All possible combinations can be covered.
- Analysis is straightforward, as there is no aliasing.

Disadvantages of full factorial DOEs:

- The cost of the experiment increases as the number of factors increases. For instance, in a two-factor two-level experiment (2^2), four runs are needed to cover the effect of A, B, AB, and the grand mean. In a five-factor two-level experiment (2^5), thirty-two runs are required to do a full factorial. Many of these runs are used to evaluate higher order interactions that the Black Belt may not be interested in. In a 2^5 experiment, there are five one-way effects (A,B,C,D,E), ten two-ways, ten three-ways, five four-ways, and one five-way effect. The 2^2 experiment has 75% of its runs spent learning about the likely one-way and two-way effects, while the 2^5 design only spends less than 50% of its runs examining these one-way and two-way effects.

Advantages of fractional factorial DOEs:

- Less money and effort is spent for the same amount of data.
- It takes less time to do fewer experiments.
- If data analysis indicates, runs can be added to eliminate confounding.

Disadvantages of fractional factorial DOEs:

- Analysis of higher order interactions could be complex.
- Confounding could mask factor and interaction effects.

How do I set up a fractional factorial DOE?

The effect of confounding should be minimized when setting up a fractional factorial. The Yates standard order will show the level settings of each factor and a coded value for all the interactions. For example, when A is high (+1) and B is low (-1), the interaction factor AB is (+1 x -1 = -1).

A column for each interaction can thus be constructed as shown here:

Level Settings and Interactions

						Factor D
A	B	C	A x B	A x C	B x C	AxBxC
-1	-1	-1	1	1	1	-1
1	-1	-1	-1	-1	1	1
-1	1	-1	-1	1	-1	1
1	1	-1	1	-1	-1	-1
-1	-1	1	1	-1	-1	1
1	-1	1	-1	1	-1	-1
-1	1	1	-1	-1	1	-1
1	1	1	1	1	1	1

Running a full factorial experiment with one more factor (D) would require a doubling of the number of runs. If factor D settings are substituted for a likely insignificant effect, that expense can be saved. The highest interaction is the least likely candidate to have a significant effect.

In this case, replacing the A x B x C interaction with factor D allows the Black Belt to say ABC was aliased or confounded with D.

(**Note**: The three-level interaction still exists, but will be confounded with the factor D. All credit for any output change will be attributed to factor D. This is a direct application of the sparsity of effects principle.)

In fact there is more aliasing than just D and ABC. Aliasing two-way and three-way effects can also be accomplished and can be computed in two ways:

1. By multiplying any two columns together (such as column A and column D), each of the values in the new column (AD) will be either -1 or +1. If the resulting column matches any other (in this case, it will match column BC), those two effects can be said to be confounded.
2. The Identity value (I) can be discovered and multiplied to get the aliased values. For example, in this case, because D=ABC (also called the design generator), the Identity value is ABCD. Multiplying this Identity value by a factor will calculate its aliases. Multiplying ABCD and D will equal ABCDD. Because any column multiplied by itself will create a column of 1's (multiplication identity), the D^2 term drops out, leaving ABC and reaffirming that D=ABC. The entire aliasing structure for this example is shown on the next page.

Aliasing Structure

Runs: 8 Fraction: 1/2
Design Generators: D = ABC
Alias Structure
I + ABCD

A + BCD	AB + CD
B + ACD	AC + BD
C + ABD	AD + BC
D + ABC	

What fractional factorials are available?

Adding an additional factor to a full factorial without adding any additional runs will create a half fractional design. (The design has half the runs needed for a full factorial. If a design has one-quarter the runs needed for full factorial analysis, it is a quarter fractional design, etc.) The key to selecting the type of run and number of factors is to understand what the resolution of the design is, for any given number of factors and available runs. The Black Belt must decide how much confounding he or she is willing to accept. A partial list of fractional designs is included below.

Number of Factors	Number of Runs	Fraction	Resolution
3	4	Half	III
4	8	Half	IV
5	8	Quarter	III
5	16	Half	V
6	8	Eighth	III
6	16	Quarter	IV
6	32	Half	VI

What is Response Surface Method?

The Response Surface Method (RSM) is a technique that enables the Black Belt to find the optimum condition for a response (y) given two or more significant factors (x's).

For the case of two factors, the basic strategy is to consider the graphical representation of the yield as a function of the two significant factors. The RSM graphic is similar to the contours of a topographical map. The higher up the "hill," the better the yield. Data is gathered to enable the contours of the map to be plotted. Once done, the resulting map is used to find the path of steepest ascent to the maximum or steepest descent to the minimum. The ultimate RSM objective is to determine the optimum operating conditions for the system or to determine a region of the factor space in which the operating specifications are satisfied (usually using a second-order model).

RSM terms:

- The *response surface* is the surface represented by the expected value of an output modeled as a function of significant inputs (variable inputs only):

$$\text{Expected (y)} = f\,(x_1, x_2, x_3, \ldots x_n)$$

- The *method of steepest ascent* or *descent* is a procedure for moving sequentially along the direction of the maximum increase (steepest ascent) or maximum decrease (steepest descent) of the response variable using the first-order model:

$$\text{y (predicted)} = \beta_0 + \Sigma\, \beta_i\, x_i$$

- The *region of curvature* is the region where one or more of the significant inputs will no longer conform to the first-order model. Once in this region of operation, most responses can be modeled using the following fitted second-order model:

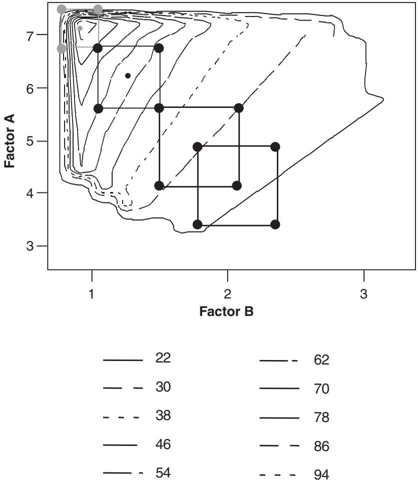
$$y \text{ (predicted)} = \beta_0 + \Sigma\, \beta_i\, x_i + \Sigma\, \beta_{ii}\, x_i\, x_{i\,+} + \Sigma\, \beta_{ij}\, x_i\, x_j$$

- The *central composite design* is a common DOE matrix used to establish a valid second-order model.

How do I do it?

1. **Select the y. Select the associated confirmed x's and boldly select their experimental ranges.**
   - These x's should have been confirmed to have a significant effect on the y through prior experimentation.
2. **Add center points to the basic 2^{k-p} design.**
   - A center point is a point halfway between the high and low settings of each factor.
3. **Conduct the DOE and plot the resulting data on a response surface.**
4. **Determine the direction of steepest ascent to an optimum y.**
5. **Reset the x values to move the DOE in the direction of the optimum y.**
   - In general, the next DOE should have x values that overlap those used in the previous experiment.
6. **Continue to conduct DOEs, evaluate the results, and step in the direction of the optimal y until a constraint has been encountered or the data shows that the optimum has been reached.**

An Example RSM Graphic

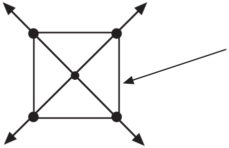


7. **Add additional points to the last design to create a central composite design to allow for a second-order evaluation. (The central composite design is described later in this chapter.)**

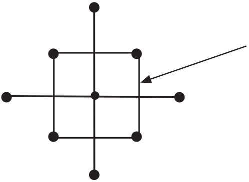
    - This will verify if the analysis is at a maximum or minimum condition. If the condition is at an optimum solution, then the process is ended. If the second-order evaluation shows that the condition is not yet at optimum, it will provide direction for the next sequential experiment.

An illustration of a central composite design for two factors is shown below.

Central Composite Design



Note that the factorial design (with center points) gives us four directions we can move.



If we add a few more points, we can significantly increase the predictive capability of the design. This *central composite* DOE is commonly used for response surface analysis. Central composite designs also allow for a true estimation of the quadratic terms in a second-order model.

RSM is intended to be a sequence of experiments with an attempt to "dial in to an optimum setting." Whenever an apparent optimum is reached, additional points are added to perform a more rigorous second-order evaluation.

What is a Box-Behnken design?

A Box-Behnken design looks like a basic factorial design with a center point, except that the corner points are missing and replaced with points on the edges. This type of design is used when the corner point settings are impossible or impractical because of their combined severity. Running three factors at their high settings could produce a volatile situation.

Advantages:

- It is more efficient than three-level full factorials.
- It is excellent for trials where corner points are not recommended.
- It allows all two-factor interactions to be modeled.
- It can identify interactions and quadratic effects.

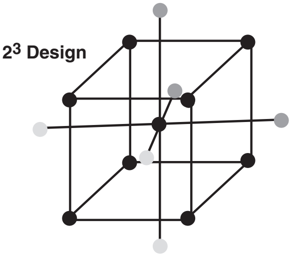
Disadvantages:

- Enough trials must be run to estimate all one-way and two-way effects (even if only one-way effects are of interest).
- It is hard to modify into other studies.

What is a Box-Wilson (central composite) design?

A Box-Wilson design is a rotatable design (subject to number of blocks) that allows for the identification of nonlinear effects. Rotatability is the characteristic that ensures constant prediction variance at all points equidistant from the design center and thus improves the quality of prediction. The design consists of a cube portion made up from the characteristics of 2^k factorial designs or 2^{k-n} fractional factorial designs, axial points, and center points.

Box-Wilson Design



Factor A	Factor B	Factor C
-1	-1	-1
1	-1	-1
-1	1	-1
1	1	-1
-1	-1	1
1	-1	1
-1	1	1
1	1	1
-1.68179	0	0
1.68179	0	0
0	-1.68179	0
0	1.68179	0
0	0	-1.68179
0	0	1.68179
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0

Advantages:

- It is a highly efficient second-order modeling design for quantitative factors.
- It can be created by adding additional points to a 2^{k-p} design, provided the original design was at least Resolution V or higher.

Disadvantages:

- It does not work with qualitative factors.
- Axial points may exceed the settings of the simple model and may be outside the ability of the process to produce.

What is a Plackett-Burman design?

Plackett-Burman designs are orthogonal designs of Resolution III that are primarily used for screening designs. Each two-way interaction is positively or negatively aliased with a main effect.

Advantages:

- A limited number of runs are needed to evaluate a lot of factors.
- Clever assignment of factors might allow the Black Belt to determine which factor caused the output, despite aliasing.

Disadvantages:

- It assumes the interactions are not strong enough to mask the main effects.
- Aliasing can be complex.

What are EVOP and PLEX designs?

Evolutionary operation (EVOP) is a continuous improvement design. Plant experimentation (PLEX) is a sequence of corrective designs meant to obtain rapid improvement. Both designs are typically small full factorial designs with possible center points. They are designed to be run while maintaining production; therefore, the inference space is typically very small.

Advantages:

- They do not disrupt production and can be used in an administrative situation.
- They force the organization to investigate factor relationships and prove factory physics.

Disadvantages:

- They can be time-consuming. For example, because, in PLEX, levels are generally set conservatively to ensure that production is not degraded, it is sometimes difficult to prove statistical validity with a single design. A first design may be used to simply decide factor levels for a subsequent design.
- They require continuous and significant management support.

What are Taguchi designs?

Taguchi designs are orthogonal designs that have, as a primary goal, finding factor settings that minimize response variation, while adjusting the process (or keeping it on target). This is called robust parameter design. The solution will reduce variation of the process and/or reduce sensitivity to noise. (Details of Taguchi designs are beyond the scope of this book. For more detailed information, see *Design of Experiments Using the Taguchi Approach: 16 Steps to Product and Process Improvement* by Ranjit K. Roy.)

Failure Mode and Effects Analysis

Why use it?

Failure Mode and Effects Analysis (FMEA) allows an assessment of the risk to customers if a key process input (x) were to fail. The FMEA also helps to determine what actions to take to minimize this risk. (The customer could be the end user of a product or a downstream operation in an organization.) FMEAs are also used to document processes and process improvement activities.

Note: There are a number of different FMEAs including design, systems, product, and process FMEAs. This chapter describes process FMEAs.

What does it do?

The FMEA provides a documented summary of the team's thoughts regarding risk to the customer if any of the key process inputs to the process fails. Furthermore, the FMEA contains the recommended and implemented actions to minimize this risk. It is a living document that must be reviewed and updated whenever the process has been modified.

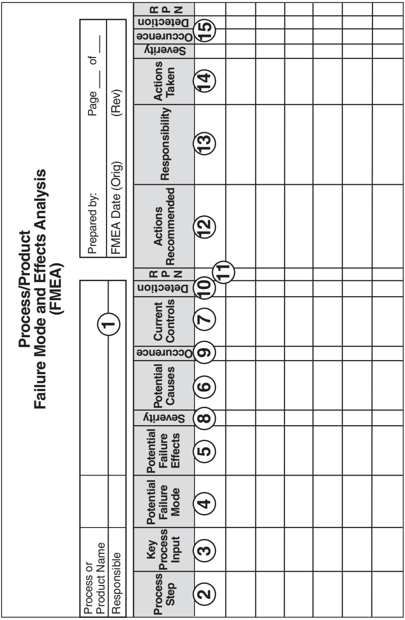
Initially, the FMEA is completed in the Measure phase of DMAIC and can provide recommended actions for the team to minimize risk to the customer. Revisions to the FMEA continue into the Analyze and Improve phases to ensure that the evaluation criteria (severity, occurrence, and detection) and cause/effect relationships are updated with data-driven conclusions. During the Control phase, the FMEA needs to be updated to reflect the final state of the improved project. The information from the FMEA will then be summarized in the control plan document and given to the process owner.

How do I do it?

The initial information needed for an FMEA is a list of Key Process Input Variables (x's). This list of x's can come from process maps, a Cause and Effect Matrix, a Cause & Effect Diagram/brainstorming session, or existing process data.

The following figure shows a typical process FMEA form. The description that follows is the method used to complete this form. (The numbers correspond to the numbers in the graphic.)

A Typical FMEA Form



Process/Product Failure Mode and Effects Analysis (FMEA)

Process or Product Name	①	Prepared by:	Page ___ of ___
Responsible		FMEA Date (Orig)	(Rev)

Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	Severity	Potential Causes	Occurence	Current Controls	Detection	RPN	Actions Recommended	Responsibility	Actions Taken	Severity	Occurence	Detection	RPN
②	③	④	⑤	⑧	⑥	⑨	⑦	⑩	⑪	⑫	⑬	⑭		⑮		

1. Include information to identify who completed the form, when the form was completed, and what process the form represents.
2. List the process step from which the key process input (x) is controlled.
3. List the specific key process input (x) of interest.
4. List the potential failure modes for this key process input. (**Note**: There may be more than one failure mode.) Describe the failure mode(s) in physical or technical terms, not as a symptom (effect) noted by the customer.
5. If the key process input (x) fails, list the effect that the customer experiences. For example, if a fitting on a brake hose was not properly adjusted, the customer would experience "loss of brake pressure."
6. List the potential cause(s) for this failure mode. There may be more than one cause per failure mode. Also consider operating conditions, usage or in-service, and possible combinations as potential causes.
7. List the controls that are currently in place to detect the cause of the failure mode.
8. On a scale from 1-10, rate the severity of the failure effect the customer experiences.
9. On a scale from 1-10, determine how often the cause of the failure mode occurs.
10. On a scale from 1-10, determine how effective the current controls can detect the cause of the failure mode. If a good detection system (such as an automated feedback system) is in place, assign a 1 or 2 to this column. If no controls are in place, assign a 10 to this column.

Note: A typical ranking system for steps 8, 9, and 10 is shown in the following figure:

FMEA Rankings

	Rating	Severity	Occurrence	Detection
High	10	Hazardous without warning	Very high and almost inevitable	Cannot detect, or detection with very low probability
		Loss of primary function	High repeated failures	Remote or low chance of detection
		Loss of secondary function	Moderate failures	Low detection probability
		Minor defect	Occasional failures	Moderate detection probability
Low	1	No effect	Failure unlikely	Almost certain detection

11. Multiply the severity, occurrence, and detection ratings together to calculate a risk priority number (RPN). The highest possible RPN would be 1000 and the lowest RPN would be 1. Low values indicate lower risk. The RPN is one indicator as to which key process inputs (x) recommended actions should be identified for, to reduce risk to the customer (step 12). If, however, any key process inputs (x) have a severity rating of 9 or 10, efforts should first focus on these key process inputs to ensure detection is at least a 1 or 2 and occurrence is also a low number.

12. Use the RPN to determine and discuss what recommended action will be taken to minimize risk to the customer.

    Note: Recommended actions can only impact detection or occurrence. The severity cannot change unless the product, service, or information is used for a different intent. If a high severity rating is observed, consider speaking to the process designers to determine if this key process input can be designed out of the process.

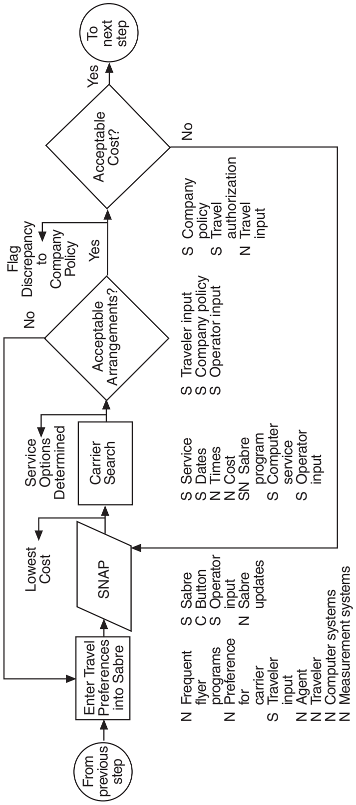
13. Identify the person responsible for completing the recommended action. Include the person's name, not his or her job function, as well as the anticipated completion date.
14. After the assigned person has completed the recommended actions, list the specific actions taken, along with the actual completion date.
15. Based on the completed actions, reevaluate the severity, occurrence, and detection to calculate a new risk priority number.

Current controls from the FMEA should be noted in the initial control plan. The FMEA needs to be updated after the project is completed but prior to handing off to the process owner, to reflect the completed project. The final FMEA will be used to finalize the control plan. If, in the future, changes are made to the process, the FMEA will need to be reviewed and updated.

Example:

A Black Belt working for a national travel agency was interested in determining why there were large discrepancies between the booked cost of airline tickets and computer-generated "lowest cost fares." These cost overruns had to be resolved to maintain one of the agency's largest corporate clients. Having performed a Cause and Effect Matrix on the process, the Black Belt narrowed his focus to five process steps thought to be highly correlated with the customer requirement of "lowest cost fares." ("SNAP" is the name of a button on the travel agency's Sabre computer system.) A segment of the detailed process map being evaluated is shown on the following page.

Travel Agency Process Map



Shown in the following figure is a portion of the completed FMEA.

The Travel Agency FMEA

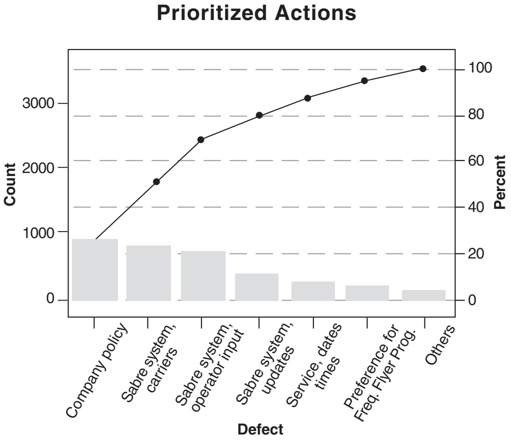
Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	Severity	Potential Causes	Occurence	Current Controls	Detection	RPN	Actions Recommended	Responsibility	Actions Taken	Severity	Occurence	Detection	RPN
Travel Prefs.	Pref. for Freq. Flyer Prog.	Lowest cost fare rejected by traveler	Flight not booked at lowest cost fare	10	Traveler override at low cost fare for frequent flyer	6	Comp. pol. restrictions and agent familiarity with policy	4	240	Data collection plan to determine number of defects for this cause	BB to create a plan for team review by Friday					0
Travel Prefs.	Traveler pref. for carrier	Lowest cost fare rejected by traveler	Flight not booked at lowest cost fare	10	Traveler pref. for carrier	4	Comp. pol. restrictions and agent familiarity with policy	4	160	Data collection plan to determine number of defects for this cause	BB to create a plan for team review by Friday					0
SNAP	Sabre-system operator input	SNAP not activated to search for lowest fare	Flight not booked at lowest cost fare	10	Agent forgot to SNAP	5	None; SNAP is only a push of the button but not regulated/ detected as part of standard operations	10	500	Data collection plan to determine number of transactions that are not SNAP'ed; Mistake-proof system so that SNAP is automatic	BB to create a plan for team review by Friday	Data collection; Use of SNAP is not consistent between operators; Fairly consistent within operator; Automated the SNAP function	10	1	1	10

Continued on the next page

The Travel Agency FMEA, continued

SNAP	Sabre-system operator input	Agent unable to use SNAP function (disabled)	Flight not booked at lowest cost fare	10	Sabre system down	2	Agency at mercy of Sabre system; No control; over Sabre system up/down time	10	200	Determine % system downtime and times of occurrence	BB and JC; Sabre point of contact for agency					0
Accept Cost	Comp. Policy	Comp. policy not adhered to	Flight not booked at lowest cost fare	10	Agent not informed/ trained on client company policy/ restrictions	5	Agents receive 8 weeks of training at hire; Policy books intended for update within request	8	400	Provide updates policies and refresher training; enable electronic capture of red-flags	SA & AK to eval. updates & training; IT for ability					0
Accept Cost	Comp. Policy	Old policy followed	Traveler override not placed on red-flag report to client billing	7	Policy not updated; Operator does not flag	4	Policies are supposed to be updated within 7 days of client request	10	280	Provide updates to policies and refresher training; One source on web	SA & AK to eval. updates & training; IT for for ability					0

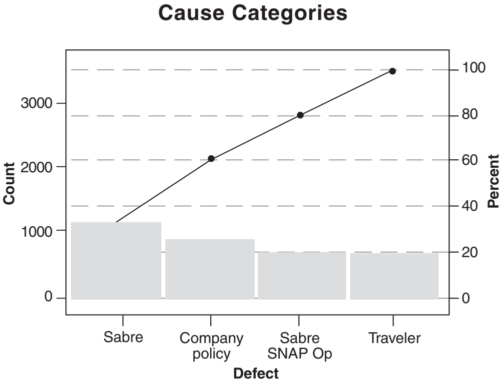
Results of the FMEA and a list of prioritized actions were summarized using a Pareto Chart, as shown in the following figure:



Count	960	800	700	400	290	240	160
Percent	27.0	22.5	19.7	11.3	8.2	6.8	4.5
Cum %	27.0	49.6	69.3	80.6	88.7	95.5	100.0

The Pareto Chart of the FMEA RPNs indicates which process inputs are the potential Key Process Input Variables that exhibit the greatest leverage on the cost of fares. The category with the highest RPN would be the best place for the Black Belt to focus on.

The Black Belt also categorized the inputs into related causes and created a Pareto Chart to sum the results, as shown on the next page.



Count	1200	960	700	690
Percent	33.8	27.0	19.7	19.4
Cum %	33.8	60.8	80.6	100.0

The Black Belt recognized that most of the Sabre-related issues were out of the team's control.

The FMEA indicated that the Black Belt needed to create a data collection plan to validate assumptions in remaining areas. The FMEA would need to be updated as progress on the project continued.

Control Charts

Why use it?

Control Charts are used to monitor, control, and improve process performance over time by studying variation and its source.

What does it do?

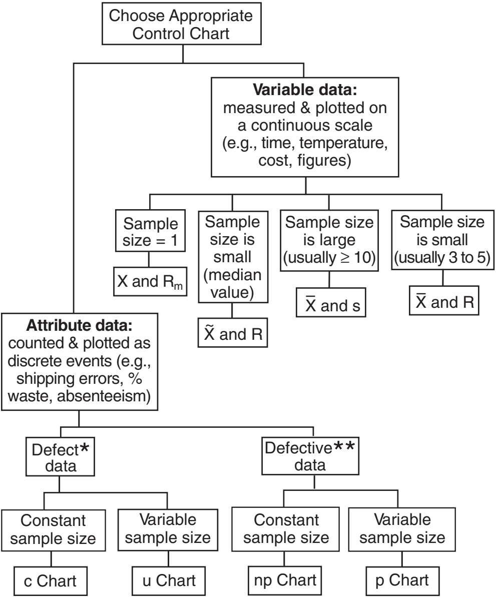
A Control Chart:

- Focuses attention on detecting and monitoring process variation over time.
- Distinguishes special from common causes of variation, as a guide to local or management action.
- Serves as a tool for ongoing control of a process.
- Helps improve a process to perform consistently and predictably for higher quality, lower cost, and higher effective capacity.
- Provides a common language for discussing process performance.

How do I do it?

There are many types of Control Charts. The Control Chart(s) that a team decides to use will be determined by the type of data it has. The Tree Diagram on the next page will help to determine which Control Chart(s) will best fit each particular situation.

Choose the appropriate Control Chart based on the type of data and sample size.



* A *defect* is a failure to meet one of the acceptance criteria. A defective unit might have multiple defects.

** *Defective* is when an entire unit fails to meet acceptance criteria, regardless of the number of defects on the unit.

Constructing Control Charts

1. **Select the process to be charted.**

2. **Determine the sampling method and plan.**

    - To determine how large a sample can be drawn, balance the time and cost to collect a sample with the amount of information that will be gathered. For attribute charts the suggested sample size is at least fifty, and for variable data charts a suggested minimum is three to five. For a c or u chart, the sample needs to be large enough to average five or more defects per lot.

    - As much as possible, obtain the samples under the same technical conditions: the same machine, operator, lot, and so on.

    - Frequency of sampling will depend on an ability to discern patterns in the data. Consider hourly, daily, shifts, monthly, annually, lots, and so on. Once the process is "in control," consider reducing the frequency with which samples are chosen.

    - Generally, collect 20–25 groups of samples before calculating the statistics and control limits.

    Tip Make sure samples are random. To establish the inherent variation of a process, allow the process to run untouched (i.e., according to standard procedures).

3. **Initiate data collection.**

    - Run the process untouched and gather sampled data.

    - Record data on an appropriate Control Chart sheet or other graph paper. Include any unusual events that occur.

4. Calculate the appropriate statistics.

a) If attribute data was collected, use the Attribute Data Table, Central Line column.

Attribute Data Table

Type Control Chart	Sample Size	Central Line	Control Limits
Fraction defective p Chart	Variable (usually ≥ 50)	For each subgroup: $p = np/n$ For all subgroups: $\bar{p} = \Sigma np/\Sigma n$	$^*UCL_p = \bar{p} + 3\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$ $^*LCL_p = \bar{p} - 3\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$
Number defective np Chart	Constant (usually ≥ 50)	For each subgroup: np = # defective units For all subgroups: $n\bar{p} = \Sigma np/k$	$UCL_{np} = n\bar{p} + 3\sqrt{n\bar{p}(1 - \bar{p})}$ $LCL_{np} = n\bar{p} - 3\sqrt{n\bar{p}(1 - \bar{p})}$
Number of defects c Chart	Constant	For each subgroup: c = # defects For all subgroups: $\bar{c} = \Sigma c/k$	$UCL_c = \bar{c} + 3\sqrt{\bar{c}}$ $LCL_c = \bar{c} - 3\sqrt{\bar{c}}$
Number of defects per unit u Chart	Variable	For each subgroup: $u = c/n$ For all subgroups: $\bar{u} = \Sigma c/\Sigma n$	$^*UCL_u = \bar{u} + 3\sqrt{\frac{\bar{u}}{n}}$ $^*LCL_u = \bar{u} - 3\sqrt{\frac{\bar{u}}{n}}$

np = # defective units
c = # of defects
n = sample size within each subgroup
k = # of subgroups

* This formula creates changing control limits. To avoid this, use average sample sizes $\bar{n}$ for those samples that are within ±20% of the average sample size. Calculate individual limits for the samples exceeding ±20%.

b)If variable data was collected, use the Variable Data Table, Central Line column.

Variable Data Table

Type Control Chart	Sample Size n	Central Line*	Control Limits
Average & Range	<10, but usually 3 to 5	$\bar{\bar{X}} = \frac{(\bar{X}_1+\bar{X}_2+\ldots\bar{X}_k)}{k}$	$UCL_{\bar{x}} = \bar{\bar{X}} + A_2\bar{R}$ $LCL_{\bar{x}} = \bar{\bar{X}} - A_2\bar{R}$
$\bar{X}$ and R		$\bar{R} = \frac{(R_1+R_2+\ldots R_k)}{k}$	$UCL_R = D_4\bar{R}$ $LCL_R = D_3\bar{R}$
Average & Standard Deviation	Usually ≥10	$\bar{\bar{X}} = \frac{(\bar{X}_1+\bar{X}_2+\ldots\bar{X}_k)}{k}$	$UCL_{\bar{X}} = \bar{\bar{X}} + A_3\bar{s}$ $LCL_{\bar{X}} = \bar{\bar{X}} - A_3\bar{s}$
$\bar{X}$ and s		$\bar{s} = \frac{(s_1+s_2+\ldots s_k)}{k}$	$UCL_s = B_4\bar{s}$ $LCL_s = B_3\bar{s}$
Median & Range	<10, but usually 3 or 5	$\bar{\tilde{X}} = \frac{(\tilde{X}_1+\tilde{X}_2+\ldots\tilde{X}_k)}{k}$	$UCL_{\tilde{X}} = \bar{\tilde{X}} + \tilde{A}_2\bar{R}$ $LCL_{\tilde{X}} = \bar{\tilde{X}} - \tilde{A}_2\bar{R}$
$\tilde{X}$ and R		$\bar{R} = \frac{(R_1+R_2+\ldots R_k)}{k}$	$UCL_R = D_4\bar{R}$ $LCL_R = D_3\bar{R}$
Individuals & Moving Range	1	$\bar{X} = \frac{(X_1+X_2+\ldots X_k)}{k}$	$UCL_X = \bar{X} + E_2\bar{R}_m$ $LCL_X = \bar{X} - E_2\bar{R}_m$
X and R_m		$R_m = \lvert(X_{i+1} - X_i)\rvert$ $\bar{R}_m = \frac{(R_1+R_2+\ldots R_{k-1})}{k-1}$	$UCL_{Rm} = D_4\bar{R}_m$ $LCL_{Rm} = D_3\bar{R}_m$

k = # of subgroups, $\tilde{X}$ = median value within each subgroup

* For constant size subgroups only

5. **Calculate the control limits.**

   a)For attribute data, use the Attribute Data Table, Control Limits column.

   b)For variable data, use the Variable Data Table, Control Limits column for the correct formula to use.

   - Use the Table of Constants (on the next page) to match the numeric values to the constants in the formulas shown in the Control Limits column of the Variable Data Table. The values to look up will depend on the type of Variable Control Chart chosen and on the size of the sample drawn.

Tip If the Lower Control Limit (LCL) of an Attribute Data Control Chart is a negative number, set the LCL to zero.

Tip The p and u formulas create changing control limits if the sample sizes vary subgroup to subgroup. To avoid this, use the average sample size n for those samples that are within ±20% of the average sample size. Calculate individual limits for the samples exceeding ±20%.

6. **Construct the Control Chart(s).**

   - For Attribute Data Control Charts, construct one chart, plotting each subgroup's proportion or number defective, number of defects, or defects per unit.

   - For Variable Data Control Charts, construct two charts: on the top chart, plot each subgroup's mean, median, or individuals, and on the bottom chart, plot each subgroup's range or standard deviation.

Table of Constants

Sample Size n	$\bar{X}$ and R Chart			$\bar{X}$ and s Chart			
	A_2	D_3	D_4	A_3	B_3	B_4	c_4*
2	1.880	0	3.267	2.659	0	3.267	.7979
3	1.023	0	2.574	1.954	0	2.568	.8862
4	0.729	0	2.282	1.628	0	2.266	.9213
5	0.577	0	2.114	1.427	0	2.089	.9400
6	0.483	0	2.004	1.287	0.030	1.970	.9515
7	0.419	0.076	1.924	1.182	0.118	1.882	.9594
8	0.373	0.136	1.864	1.099	0.185	1.815	.9650
9	0.337	0.184	1.816	1.032	0.239	1.761	.9693
10	0.308	0.223	1.777	0.975	0.284	1.716	.9727

Sample Size n	$\tilde{X}$ and R Chart			X and R_m Chart			
	$\tilde{A}_2$	D_3	D_4	E_2	D_3	D_4	d_2*
2	- - - -	0	3.267	2.659	0	3.267	1.128
3	1.187	0	2.574	1.772	0	2.574	1.693
4	- - - -	0	2.282	1.457	0	2.282	2.059
5	0.691	0	2.114	1.290	0	2.114	2.326
6	- - - -	0	2.004	1.184	0	2.004	2.534
7	0.509	0.076	1.924	1.109	0.076	1.924	2.704
8	- - - -	0.136	1.864	1.054	0.136	1.864	2.847
9	0.412	0.184	1.816	1.010	0.184	1.816	2.970
10	- - - -	0.223	1.777	0.975	0.223	1.777	3.078

* Useful in estimating the process standard deviation $\hat{\sigma}$.

Note: The minimum sample size shown in this chart is 2 because variation in the form of a range can only be calculated in samples greater than 1. The X and R_m Chart creates these minimum samples by combining and then calculating the difference between sequential, individual measurements.

- Draw a solid horizontal line on each chart. This line corresponds to the process average.
- Draw dashed lines for the upper and lower control limits.

Interpreting Control Charts

- *Attribute Data Control Charts* are based on one chart. The charts for fraction or number defective, number of defects, or number of defects per unit, measure variation *between samples*. *Variable Data Control Charts* are based on two charts: the one on top, for averages, medians, and individuals, measures variation *between subgroups* over time; the chart below, for ranges and standard deviations, measures variation *within subgroups* over time.
- Determine if the process mean (center line) is where it should be relative to customer specifications or internal business needs or objectives. If not, then it is an indication that something has changed in the process, the customer requirements or objectives have changed, or the process has never been centered.
- Analyze the data relative to the control limits; distinguish between *common* causes and *special* causes. The fluctuation of the points within the limits results from variation inherent in the process. This variation results from common causes within the system (e.g., design, choice of machine, preventive maintenance) and can only be affected by changing that system. However, points outside of the limits or patterns within the limits come from a special cause (e.g., human errors, unplanned events, freak occurrences) that is not part of the way the process normally operates, or is present because of an unlikely

combination of process steps. Special causes must be eliminated before the Control Chart can be used as a monitoring tool. Once this is done, the process will be "in control" and samples can be taken at regular intervals to make sure that the process doesn't fundamentally change. (See the "Determining if the Process is Out of Control" section of this chapter.)

- A process is in "statistical control" if the process is not being affected by special causes (the influence of an individual or machine). All the points must fall within the control limits and they must be randomly dispersed about the average line for an in-control system.

Tip "Control" doesn't necessarily mean that the product or service will meet the needs. It only means that the process is *consistent.* Don't confuse control limits with specification limits—specification limits are related to customer requirements, not process variation.

Tip Any points outside the control limits, once identified with a cause (or causes), should be removed and the calculations and charts redone. Points within the control limits, but showing indications of trends, shifts, or instability, are also special causes.

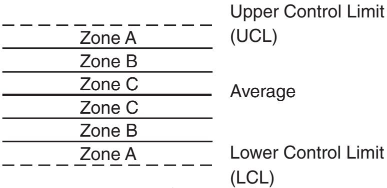
Tip When a Control Chart has been initiated and all special causes removed, continue to plot new data on a new chart, but DO NOT recalculate the control limits. As long as the process does not change, the limits should not be changed. Control limits should be recalculated only when a permanent, desired change has occurred in the process, and only using data *after* the change occurred.

Tip Nothing will change just because a chart was created! An action must occur. Form a team to investigate. (See the "Common Questions for Investigating an Out-of-Control Process" list in this chapter.)

Determining if the Process is Out of Control

A process is said to be "out of control" if either one of these is true:

1. **One or more points fall outside of the control limits.***
2. **When the Control Chart is divided into zones, as shown below, any of the following points are true:**



a) Two points, out of three consecutive points, are on the same side of the average in Zone A or beyond.

b) Four points, out of five consecutive points, are on the same side of the average in Zone B or beyond.

c) Nine consecutive points are on one side of the average.

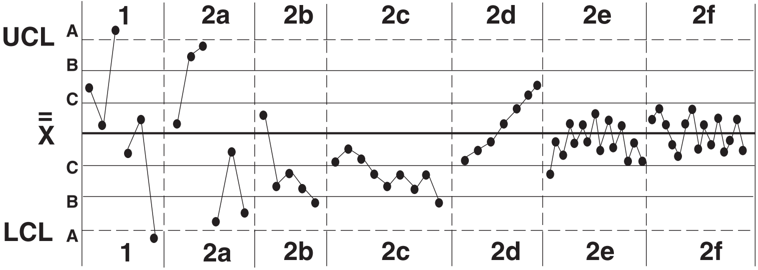
d) There are six consecutive points, increasing or decreasing.*

e) There are fourteen consecutive points that alternate up and down.*

f) There are fifteen consecutive points within Zone C (above and below the average).

* Applies for both variable and attribute data

Tests for Control



Source: Lloyd S. Nelson, Director of Statistical Methods, Nashua Corporation, New Hampshire

Common Questions for Investigating an Out-of-Control Process

☐ Yes ☐ No Are there differences in the measurement accuracy of instruments/methods used?

☐ Yes ☐ No Are there differences in the methods used by different personnel?

☐ Yes ☐ No Is the process affected by the environment (e.g., temperature, humidity)?

☐ Yes ☐ No Has there been a significant change in the environment?

☐ Yes ☐ No Is the process affected by predictable conditions (e.g., tool wear)?

☐ Yes ☐ No Were any untrained personnel involved in the process at the time?

☐ Yes ☐ No Has there been a change in the source for input to the process (e.g., raw materials, information)?

☐ Yes ☐ No Is the process affected by employee fatigue?

☐ Yes ☐ No Has there been a change in policies or procedures (e.g., maintenance procedures)?

☐ Yes ☐ No Is the process adjusted frequently?

☐ Yes ☐ No Did the samples come from different parts of the process? Shifts? Individuals?

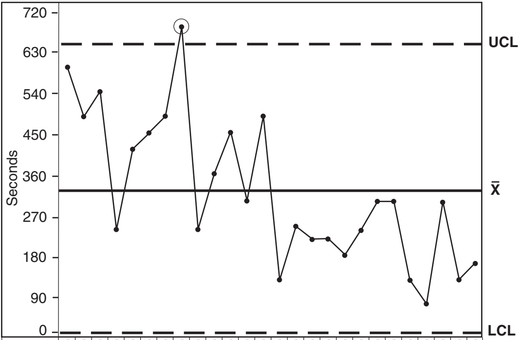
☐ Yes ☐ No Are employees afraid to report "bad news"?

A team should address each "Yes" answer as a potential source of a special cause.

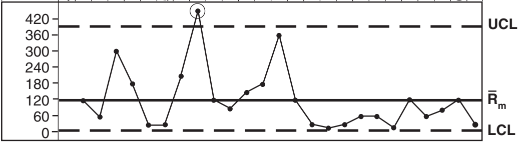
Individuals & Moving Range Chart

IV Lines Connection Time

Process/Operation: IV Lines Connection Open Heart Admissions			**Department:** Intensive Care
Characteristic: Time in seconds	**Sample Size:** One	**Sample Frequency:** Each patient	**By:** EW **Date:** 6/10
Individuals: **k** = 26 **Ranges:** **n** = 2	$\sum$**X** = 8470 $\sum$**R** = 2990	$\bar{\bar{X}}$ = 325.77 $\bar{R}$ = 119.6	**UCL** = 645 **LCL** = 7 **UCL** = 392 **LCL** = 0



X	600	480	540	240	420	450	480	690	240	360	450	300	480	120	240	210	210	180	240	300	300	130	120	300	180	210
R_m	—	120	60	300	180	30	30	210	450	120	90	150	180	360	120	30	0	30	60	60	0	120	60	80	120	30
Who?	EW	EW	EW	EW	EW	EW	EW	EW	MA	EW	EW	EW	EW	EW	EW	EW	MA	EW	EW	EW	EW	EW	EW	EW	EW	EW
When?	4/9	11	12	13	25	30	5/2	3	4	5	9	13	14	14	16	17	19	20	22	23	23	24	30	30	6/6	6



Information provided courtesy of
Parkview Episcopal Medical Center

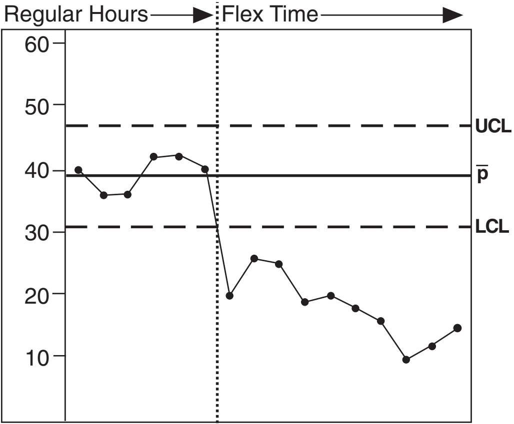
Note: Something in the process changed, and now it takes less time to make IV connections for patients being admitted for open heart surgery.

p Chart

General Dentistry: Percent of Patients Who Failed to Keep Appointments

Historical Statistics:

$\bar{p}$ = 39 **UCL** = 47 **LCL** = 31



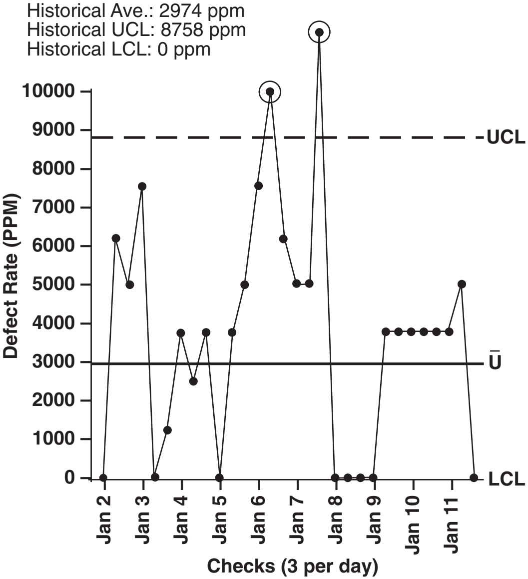
% Failed	40	36	36	42	42	40	20	26	25	19	20	18	16	10	12	12
Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Year	1992						1993									

Information provided courtesy of U.S. Navy, Naval Dental Center, San Diego

Note: Providing flex time for patients resulted in fewer appointments missed.

u Chart

Shop Process Check
Solder Defects

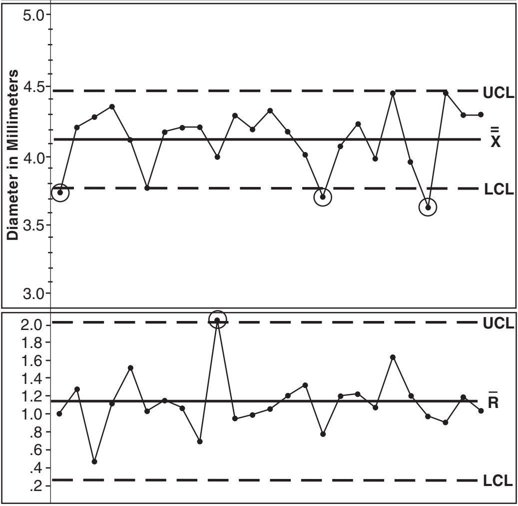


Information provided courtesy of AT&T

$\overline{X}$ & R Chart

n = 10 parts randomly sampled each hour

Hourly #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Ave.
$\overline{X}$	3.76	4.21	4.29	4.36	4.13	3.77	4.17	4.21	4.22	4.00	4.30	4.20	4.32	4.18	4.02	3.71	4.08	4.23	3.98	4.46	3.96	3.63	4.48	4.30	4.29	4.13
R	1.01	1.27	0.48	1.32	1.52	1.03	1.15	1.07	0.70	2.05	0.95	0.99	1.06	1.21	1.33	0.78	1.21	1.23	1.08	1.64	1.20	0.98	0.91	1.19	1.03	1.14



Information provided courtesy of BlueFire Partners, Inc. and Hamilton Standard

Note: Hours 1, 16 and 22 should be reviewed to understand why these sample averages are outside the control limts

Total Productive Maintenance and Preventative Maintenance

Why use it?

Total Productive Maintenance (TPM) is a program to continuously improve equipment operation through maintenance performed by both operators and maintenance personnel. These improvements to equipment maintainability are developed and implemented through small group activities.

The goals of TPM are:

- Improved effectiveness by reducing defects for both existing and new equipment over their entire life spans. Defects include both product and process defects caused by the equipment, as well as the cycle defect caused by downtime.
- Significant involvement of operators in the maintenance of their equipment (autonomous maintenance).
- Effective preventative maintenance (PM).
- The use of small group activities to maintain and improve current equipment effectiveness and to set standards for new equipment maintainability.
- Improved safety.

TPM (and PM) will mitigate losses due to:

- Breakdowns (lost capacity).
- Setup and adjustment stoppages.
- Idling and minor stoppages.
- Reduced speed due to deterioration.
- Startup and yield stoppages (worn or broken tools).
- Defects and rework.

How do I do it?

1. **Implement *autonomous maintenance*.**
   - Autonomous maintenance assigns responsibility for day-to-day lubrication, cleaning, and adjustment of equipment to the operators of that equipment.
   - It is also suggested that operators assist when maintenance craftspeople work on their machines.
2. **Implement *corrective maintenance*.**
   - Corrective maintenance involves small cross-functional groups (including operators) actively evaluating the equipment and submitting improvement ideas aimed at preventing breakdowns and the conditions that cause them.
   - The aim is to make improvements that keep equipment from breaking down, facilitate inspection, repair, and use, and ensure safety. Having the results of daily inspections and the details of all breakdowns is crucial to the success of this step.
   - Frequently, a major cleaning of the equipment by the group is a logical start to both finding issues and establishing a team.
3. **Implement *preventative maintenance*.**
   - Preventative maintenance implies an interval-based service plan with the intervals based on data. In a TPM environment, much of the PM is done by the operators (autonomous maintenance).
   - Two common measurements are mean time between failures (MTBF) and mean time to repair (MTTR). TPM, or PM by itself, will not

function well if there is great variability in the MTBF.

4. **Implement *maintenance prevention*.**
   - The findings and knowledge gained as a result of work teams analyzing current machines should lead to any new equipment being specified to ensure it is reliable, maintainable, safe, and easy to use.
5. **Improve *breakdown maintenance*.**
   - Use TPM/PM activities to drive an improved response time for those cases when sudden machine failures occur.

Overall Equipment Effectiveness

Overall equipment effectiveness (OEE) is an index to measure the overall health of the equipment. It is used to identify the worst problems.

OEE = Availability x Performance x Quality

Where:

- Availability = (Schedule time - Downtime)/ Schedule time
- Performance = (Standard time x Output)/ Operating time
- Quality = (Units total - Units defective)/ Units total

Ratio of planned vs. total maintenance

The ratio of planned maintenance vs. total maintenance is a useful metric to measure the status of TPM implementation.

Total maintenance is all recorded maintenance hours from all souces. Planned maintenance is the total maintenance less the maintenance done as a direct result of equipment breakdown. A monthly calculation of this ratio provides a barometer of the health of the TPM.

Control Plan

Why use it?

A control plan provides an institutional memory of the status of a process and the measurements that define it. It provides for timely process troubleshooting and repair, and aids in training and audit activities. It becomes a living document within the process to sustain process improvements. It also documents the control activities of a Six Sigma project prior to completion.

What does it do?

A Six Sigma control plan is a set of documents that:

- Provides a point of reference among instructions, characteristics, and specifications.
- Links Critical to Satisfaction (CTS) characteristics to the operational details of the process.
- Encompasses several process areas including operating procedures, preventative maintenance, and gauge control (MSA). (**Note**: Because of space constraints, this chapter will be limited to discussion of operating procedures.)
- Provides prevention against process drift or deviation through identified measurement methods and responsibilities as well as decision rules and SOP references.
- Empowers local control of process corrective actions and resources.
- Can provide shutdown and/or quarantine activities.

- Links Key Process Input Variables (KPIVs) to Key Process Output Variables (KPOVs).
- Ensures that a Six Sigma project is ready for completion. If a control plan cannot be completed, at least one of the key elements (identification, specification, measurement, planned response to nonconformity, or control/responsibility) has not been defined or agreed to.

How do I do it?

A sample Control Plan is shown on the next page. The numbers in the figure correspond to the numbers in the description below.

The administrative section of the control plan (sections 1-3) provides key identification, approval, and document control information. The main body of the control plan (sections 4-8) provides substantive information on the process and reactions to out-of-control conditions. The last section (sections 9 and 10) links the control plan to the final FMEA.

1. The process information area should clearly and uniquely identify the process affected by the control plan.
2. The Black Belt (or Master Black Belt) and process owners should approve of the plan.
3. The document control section provides for identification, traceability, and retrieval of the control plan document itself. For a control plan to be effective, it must be a living document; therefore, the plan must contain space to document revisions.
4. The *Subprocess* and *Subprocess Step* fields identify and define the scope of the process being controlled.
5. The *CTS* fields indicate if the subprocess step generates a KPIV (directly linked to a KPOV) or a KPOV (directly affecting the customer).

A Six Sigma Control Plan

Process Name:	Prepared by:	Page: of
Customer:	Approved by:	Document #:
Location: ①	Approved by: ②	Revision Date: ③
Area:	Approved by:	Supercedes:

Subprocess	Subprocess Step	CTS		Specification Characteristic	Specification Requirement			Measurement Method	Sample Size	Frequency	Who Measures	Where Recorded	Decision Rule/ Corrective Action	SOP Reference
		KPIV	KPOV		LSL	Target	USL							
④		⑤		⑥		⑦			⑧				⑨	

6. The *Specification Characteristic* field provides a succinct description of what is being checked/ evaluated.
7. The *Specification Requirement* fields provide inspection criteria (specification limits or attribute screening criteria).
8. The *Measurement Method*, *Sample Size*, *Frequency*, *Who Measures*, and *Where Recorded* fields define the actual evaluation details.
9. The *Decision Rule/Corrective Action* and the *SOP Reference* fields provide response instructions if the process were to show nonconformance as a result of the inspection/evaluation activities as documented in the previous fields. It should include process shutdown or quarantine authority/procedures if appropriate, and show links to where other supporting documents, procedures, or policies (such as the organization's quality system) are documented.
10. An optional *Audit* column (not shown on this form) can provide clear linkage to ISO or QS audit systems. These audits can be on the output of the process (y's), on the inputs of the process (x's), or can be designed to ensure that the project controls are still in place.

A Sample Control Plan

Process Name:	Panel Painting	**Prepared by:**	Kelly Roff	**Page:**	1 of 1
Customer:	ABC Construction (Ext)	**Approved by:**	Page Right	**Document #:**	PP-101-Rev C
Location:	Building 1204-2	**Approved by:**	Jordan Meyer	**Revision Date:**	19-Dec-02
Area:	Post N4E8, Paint	**Approved by:**		**Supercedes:**	Rev B

Subprocess	**Subprocess Step**	**CTS**		**Specification Characteristic**	**Specification Requirement**			**Measurement Method**	**Sample Size**	**Frequency**	**Who Measures**	**Where Recorded**	**Decision Rule/ Corrective Action**	**SOP Reference**
		KPIV	**KPOV**		**LSL**	**Target**	**USL**							
Coat Application	Coating Application		X	Dosage	22		23	UIL-1700	1	1/hr	Techn	Process Log	Process shutdwn Chk feed mech. per SOP	PAC-121.2
	Coating Application	X		Coating thickness	17		18	UIL-1701	35 pts per panel	1/hr	Techn	Process Log	Process shutdwn/ Check nozzle per SOP	PAC-121.3

Appendix

Standard Z Table

Z	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
-4.0	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00002	0.00002	0.00002	0.00002
-3.9	0.00005	0.00005	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00003	0.00003
-3.8	0.00007	0.00007	0.00007	0.00006	0.00006	0.00006	0.00006	0.00005	0.00005	0.00005
-3.7	0.00011	0.00010	0.00010	0.00010	0.00009	0.00009	0.00008	0.00008	0.00008	0.00008
-3.6	0.00016	0.00015	0.00015	0.00014	0.00014	0.00013	0.00013	0.00012	0.00012	0.00011
-3.5	0.00023	0.00022	0.00022	0.00021	0.00020	0.00019	0.00019	0.00018	0.00017	0.00017
-3.4	0.00034	0.00032	0.00031	0.00030	0.00029	0.00028	0.00027	0.00026	0.00025	0.00024
-3.3	0.00048	0.00047	0.00045	0.00043	0.00042	0.00040	0.00039	0.00038	0.00036	0.00035
-3.2	0.00069	0.00066	0.00064	0.00062	0.00060	0.00058	0.00056	0.00054	0.00052	0.00050
-3.1	0.00097	0.00094	0.00090	0.00087	0.00084	0.00082	0.00079	0.00076	0.00074	0.00071
-3.0	0.00135	0.00131	0.00126	0.00122	0.00118	0.00114	0.00111	0.00107	0.00103	0.00100
-2.9	0.00187	0.00181	0.00175	0.00169	0.00164	0.00159	0.00154	0.00149	0.00144	0.00139
-2.8	0.00256	0.00248	0.00240	0.00233	0.00226	0.00219	0.00212	0.00205	0.00199	0.00193
-2.7	0.00347	0.00336	0.00326	0.00317	0.00307	0.00298	0.00289	0.00280	0.00272	0.00264
-2.6	0.00466	0.00453	0.00440	0.00427	0.00415	0.00402	0.00391	0.00379	0.00368	0.00357
-2.5	0.00621	0.00604	0.00587	0.00570	0.00554	0.00539	0.00523	0.00508	0.00494	0.00480
-2.4	0.00820	0.00798	0.00776	0.00755	0.00734	0.00714	0.00695	0.00676	0.00657	0.00639
-2.3	0.01072	0.01044	0.01017	0.00990	0.00964	0.00939	0.00914	0.00889	0.00866	0.00842
-2.2	0.01390	0.01355	0.01321	0.01287	0.01255	0.01222	0.01191	0.01160	0.01130	0.01101
-2.1	0.01786	0.01743	0.01700	0.01659	0.01618	0.01578	0.01539	0.01500	0.01463	0.01426
-2.0	0.02275	0.02222	0.02169	0.02118	0.02067	0.02018	0.01970	0.01923	0.01876	0.01831

Standard Z Table, continued

Z	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
-1.9	0.02872	0.02807	0.02743	0.02680	0.02619	0.02559	0.02500	0.02442	0.02385	0.02330
-1.8	0.03593	0.03515	0.03438	0.03362	0.03288	0.03216	0.03144	0.03074	0.03005	0.02938
-1.7	0.04456	0.04363	0.04272	0.04181	0.04093	0.04006	0.03920	0.03836	0.03754	0.03673
-1.6	0.05480	0.05370	0.05262	0.05155	0.05050	0.04947	0.04846	0.04746	0.04648	0.04551
-1.5	0.06681	0.06552	0.06425	0.06301	0.06178	0.06057	0.05938	0.05821	0.05705	0.05592
-1.4	0.08076	0.07927	0.07780	0.07636	0.07493	0.07353	0.07214	0.07078	0.06944	0.06811
-1.3	0.09680	0.09510	0.09342	0.09176	0.09012	0.08851	0.08691	0.08534	0.08379	0.08226
-1.2	0.11507	0.11314	0.11123	0.10935	0.10749	0.10565	0.10383	0.10204	0.10027	0.09852
-1.1	0.13566	0.13350	0.13136	0.12924	0.12714	0.12507	0.12302	0.12100	0.11900	0.11702
-1.0	0.15865	0.15625	0.15386	0.15150	0.14917	0.14686	0.14457	0.14231	0.14007	0.13786
-0.9	0.18406	0.18141	0.17878	0.17618	0.17361	0.17105	0.16853	0.16602	0.16354	0.16109
-0.8	0.21185	0.20897	0.20611	0.20327	0.20045	0.19766	0.19489	0.19215	0.18943	0.18673
-0.7	0.24196	0.23885	0.23576	0.23269	0.22965	0.22663	0.22363	0.22065	0.21769	0.21476
-0.6	0.27425	0.27093	0.26763	0.26434	0.26108	0.25784	0.25462	0.25143	0.24825	0.24509
-0.5	0.30853	0.30502	0.30153	0.29805	0.29460	0.29116	0.28774	0.28434	0.28095	0.27759
-0.4	0.34457	0.34090	0.33724	0.33359	0.32997	0.32635	0.32276	0.31917	0.31561	0.31206
-0.3	0.38209	0.37828	0.37448	0.37070	0.36692	0.36317	0.35942	0.35569	0.35197	0.34826
-0.2	0.42074	0.41683	0.41293	0.40904	0.40516	0.40129	0.39743	0.39358	0.38974	0.38590
-0.1	0.46017	0.45620	0.45224	0.44828	0.44433	0.44038	0.43644	0.43250	0.42857	0.42465
0.0	0.50000	0.49601	0.49202	0.48803	0.48404	0.48006	0.47607	0.47209	0.46811	0.46414

Z to DPMO Conversion Table

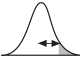
Sigma Level - Tenths	Sigma Level* - Hundreths									
	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
1.5	500,000	496,000	492,000	488,000	484,000	480,100	476,100	472,100	468,100	464,100
1.6	460,200	456,200	452,200	448,300	444,300	440,400	436,400	432,500	428,600	424,700
1.7	420,700	416,800	412,900	409,000	405,200	401,300	397,400	393,600	389,700	385,900
1.8	382,100	378,300	374,500	370,700	366,900	363,200	359,400	355,700	352,000	348,300
1.9	344,600	340,900	337,200	333,600	330,000	326,400	322,800	319,200	315,600	312,100
2.0	308,500	305,000	301,500	298,100	294,600	291,200	287,700	284,300	281,000	277,600
2.1	274,300	270,900	267,600	264,300	261,100	257,800	254,600	251,400	248,300	245,100
2.2	242,000	238,900	235,800	232,700	229,700	226,600	223,600	220,700	217,700	214,800
2.3	211,900	209,000	206,100	203,300	200,500	197,700	194,900	192,200	189,400	186,700
2.4	184,100	181,400	178,800	176,200	173,600	171,100	168,500	166,000	163,500	161,100
2.5	158,700	156,200	153,900	151,500	149,200	146,900	144,600	142,300	140,100	137,900
2.6	135,700	133,500	131,400	129,200	127,100	125,100	123,000	121,000	119,000	117,000
2.7	115,100	113,100	111,200	109,300	107,500	105,600	103,800	102,000	100,300	98,530
2.8	96,800	95,100	93,420	91,760	90,120	88,510	86,910	85,340	83,790	82,260
2.9	80,760	79,270	77,800	76,360	74,930	73,530	72,140	70,780	69,440	68,110
3.0	66,810	65,520	64,260	63,010	61,780	60,570	59,380	58,210	57,050	55,920
3.1	54,800	53,700	52,620	51,550	50,500	49,470	48,460	47,460	46,480	45,510
3.2	44,570	43,630	42,720	41,820	40,930	40,060	39,200	38,360	37,540	36,730
3.3	35,930	35,150	34,380	33,630	32,880	32,160	31,440	30,740	30,050	29,380
3.4	28,720	28,070	27,430	26,800	26,190	25,590	25,000	24,420	23,850	23,300
3.5	22,750	22,220	21,690	21,180	20,680	20,180	19,700	19,203	18,760	18,310
3.6	17,860	17,430	17,000	16,590	16,180	15,780	15,390	15,000	14,630	14,260
3.7	13,900	13,550	13,210	12,870	12,550	12,220	11,910	11,600	11,300	11,010
3.8	10,720	10,440	10,170	9,903	9,642	9,387	9,137	8,894	8,656	8,424
3.9	8,198	7,976	7,760	7,549	7,344	7,143	6,947	6,756	6,569	6,387
4.0	6,210	6,036	5,868	5,703	5,543	5,386	5,234	5,085	4,940	4,799

Z to DPMO
Conversion Table, continued

Sigma Level - Tenths	Sigma Level* - Hundredths									
	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
4.1	4,661	4,527	4,396	4,269	4,145	4,024	3,907	3,792	3,681	3,572
4.2	3,467	3,364	3,264	3,167	3,072	2,980	2,890	2,803	2,718	2,635
4.3	2,555	2,477	2,401	2,327	2,256	2,186	2,118	2,052	1,988	1,926
4.4	1,866	1,807	1,750	1,695	1,641	1,589	1,538	1,489	1,441	1,395
4.5	1,350	1,306	1,264	1,223	1,183	1,144	1,107	1,070	1,035	1,001
4.6	968	935	904	874	845	816	789	762	736	711
4.7	687	664	641	619	598	577	557	538	519	501
4.8	484	467	450	434	419	404	390	376	363	350
4.9	337	325	313	302	291	280	270	260	251	242
5.0	233	224	216	208	200	193	186	179	172	166
5.1	159	153	147	142	136	131	126	121	117	112
5.2	108	104	100	96	92	89	85	82	79	75
5.3	72	70	67	64	62	59	57	55	52	50
5.4	48	46	44	43	41	39	38	36	35	33
5.5	32	30	29	28	27	26	25	24	23	22
5.6	21.0	20.0	19.0	18.0	17.0	17.0	16.0	15.3	14.7	14.0
5.7	13.4	12.9	12.3	11.7	11.3	10.8	10.3	9.9	9.4	9.0
5.8	8.6	8.2	7.9	7.5	7.2	6.9	6.6	6.3	6.0	5.7
5.9	5.4	5.2	5.0	4.8	4.6	4.4	4.2	4.0	3.8	3.6
6.0	3.4	3.3	3.1	3.0	2.9	2.7	2.6	2.5	2.4	2.3

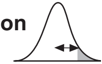
Example: 412,900 DPMO = 1.72 sigma, which, according to convention, is rounded-off to 1.7 sigma.
*1.5 sigma shift included.

Normal Distribution



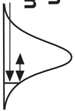
z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.4960	0.4920	0.4880	0.4840	0.4801	0.4761	0.4721	0.4681	0.4641
0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4404	0.4364	0.4325	0.4286	0.4247
0.2	0.4207	0.4168	0.4129	0.4090	0.4052	0.4013	0.3974	0.3936	0.3897	0.3859
0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483
0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
0.6	0.2743	0.2709	0.2676	0.2643	0.2611	0.2578	0.2546	0.2514	0.2483	0.2451
0.7	0.2420	0.2389	0.2358	0.2327	0.2296	0.2266	0.2236	0.2206	0.2177	0.2148
0.8	0.2119	0.2090	0.2061	0.2033	0.2005	0.1977	0.1949	0.1922	0.1894	0.1867
0.9	0.1841	0.1814	0.1788	0.1762	0.1736	0.1711	0.1685	0.1660	0.1635	0.1611
1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
1.4	0.0808	0.0793	0.0778	0.0764	0.0749	0.0735	0.0721	0.0708	0.0694	0.0681
1.5	0.0668	0.0655	0.0643	0.0630	0.0618	0.0606	0.0594	0.0582	0.0571	0.0559
1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
1.7	0.0446	0.0436	0.0427	0.0418	0.0409	0.0401	0.0392	0.0384	0.0375	0.0367
1.8	0.0359	0.0351	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
2.0	0.0228	0.0222	0.0217	0.0212	0.0207	0.0202	0.0197	0.0192	0.0188	0.0183
2.1	0.0179	0.0174	0.0170	0.0166	0.0162	0.0158	0.0154	0.0150	0.0146	0.0143
2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
2.4	0.0082	0.0080	0.0078	0.0075	0.0073	0.0071	0.0069	0.0068	0.0066	0.0064
2.5	0.0062	0.0060	0.0059	0.0057	0.0055	0.0054	0.0052	0.0051	0.0049	0.0048
2.6	0.0047	0.0045	0.0044	0.0043	0.0041	0.0040	0.0039	0.0038	0.0037	0.0036
2.7	0.0035	0.0034	0.0033	0.0032	0.0031	0.0030	0.0029	0.0028	0.0027	0.0026
2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
2.9	0.0019	0.0018	0.0018	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014
3.0	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0010
3.1	0.0010	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007
3.2	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005
3.3	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003
3.4	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
3.5	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
3.6	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
3.7	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
3.8	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
3.9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Probability Points of t Distribution with v Degrees of Freedom



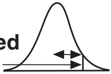
v	0.4	0.25	0.1	0.05	0.025	0.01	0.005	0.0025	0.001	0.0005
1	0.325	1.000	3.078	6.314	12.706	31.821	63.657	127.32	318.31	636.62
2	0.289	0.816	1.886	2.920	4.303	6.965	9.925	14.089	22.326	31.598
3	0.277	0.765	1.638	2.353	3.182	4.541	5.841	7.453	10.213	12.924
4	0.271	0.741	1.533	2.132	2.776	3.747	4.604	5.598	7.173	8.610
5	0.267	0.727	1.476	2.015	2.571	3.365	4.032	4.773	5.893	6.869
6	0.265	0.718	1.440	1.943	2.447	3.143	3.707	4.317	5.208	5.959
7	0.263	0.711	1.415	1.895	2.365	2.998	3.499	4.029	4.785	5.408
8	0.262	0.706	1.397	1.860	2.306	2.896	3.355	3.833	4.501	5.041
9	0.261	0.703	1.383	1.833	2.262	2.821	3.250	3.690	4.297	4.781
10	0.260	0.700	1.372	1.812	2.228	2.764	3.169	3.581	4.144	4.587
11	0.260	0.697	1.363	1.796	2.201	2.718	3.106	3.497	4.025	4.437
12	0.259	0.695	1.356	1.782	2.179	2.681	3.055	3.428	3.930	4.318
13	0.259	0.694	1.350	1.771	2.160	2.650	3.012	3.372	3.852	4.221
14	0.258	0.692	1.345	1.761	2.145	2.624	2.977	3.326	3.787	4.140
15	0.258	0.691	1.341	1.753	2.131	2.602	2.947	3.286	3.733	4.073
16	0.258	0.690	1.337	1.746	2.120	2.583	2.921	3.252	3.686	4.015
17	0.257	0.689	1.333	1.740	2.110	2.567	2.898	3.222	3.646	3.965
18	0.257	0.688	1.330	1.734	2.101	2.552	2.878	3.197	3.610	3.922
19	0.257	0.688	1.328	1.729	2.093	2.539	2.861	3.174	3.579	3.883
20	0.257	0.687	1.325	1.725	2.086	2.528	2.845	3.153	3.552	3.850
21	0.257	0.686	1.323	1.721	2.080	2.518	2.831	3.135	3.527	3.819
22	0.256	0.686	1.321	1.717	2.074	2.508	2.819	3.119	3.505	3.792
23	0.256	0.685	1.319	1.714	2.069	2.500	2.807	3.104	3.485	3.767
24	0.256	0.685	1.318	1.711	2.064	2.492	2.797	3.091	3.467	3.745
25	0.256	0.684	1.316	1.708	2.060	2.485	2.787	3.078	3.450	3.725
26	0.256	0.684	1.315	1.706	2.056	2.479	2.779	3.067	3.435	3.707
27	0.256	0.684	1.314	1.703	2.052	2.473	2.771	3.057	3.421	3.690
28	0.256	0.683	1.313	1.701	2.048	2.467	2.763	3.047	3.408	3.674
29	0.256	0.683	1.311	1.699	2.045	2.462	2.756	3.038	3.396	3.659
30	0.256	0.683	1.310	1.697	2.042	2.457	2.750	3.030	3.385	3.646
40	0.255	0.681	1.303	1.684	2.021	2.423	2.704	2.971	3.307	3.551
60	0.254	0.679	1.296	1.671	2.000	2.390	2.660	2.915	3.232	3.460
120	0.254	0.677	1.289	1.658	1.980	2.358	2.617	2.860	3.160	3.373
∞	0.253	0.674	1.282	1.645	1.960	2.326	2.576	2.807	3.090	3.291

Ordinates of t Distribution with v Degrees of Freedom



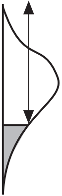
v	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
1	0.318	0.300	0.255	0.204	0.159	0.124	0.098	0.078	0.064	0.053	0.044	0.037	0.032
2	0.354	0.338	0.296	0.244	0.193	0.149	0.114	0.088	0.068	0.053	0.042	0.034	0.027
3	0.368	0.353	0.313	0.261	0.207	0.159	0.120	0.090	0.068	0.051	0.039	0.030	0.023
4	0.375	0.361	0.322	0.270	0.215	0.164	0.123	0.091	0.066	0.049	0.036	0.026	0.020
5	0.380	0.366	0.328	0.276	0.220	0.168	0.125	0.091	0.065	0.047	0.033	0.024	0.017
6	0.383	0.369	0.332	0.280	0.223	0.170	0.126	0.090	0.064	0.045	0.032	0.022	0.016
7	0.385	0.372	0.335	0.283	0.226	0.172	0.126	0.090	0.063	0.044	0.030	0.021	0.014
8	0.387	0.373	0.337	0.285	0.228	0.173	0.127	0.090	0.062	0.043	0.029	0.019	0.013
9	0.388	0.375	0.338	0.287	0.229	0.174	0.127	0.090	0.062	0.042	0.028	0.018	0.012
10	0.389	0.376	0.340	0.288	0.230	0.175	0.127	0.090	0.061	0.041	0.027	0.018	0.011
11	0.390	0.377	0.341	0.289	0.231	0.176	0.128	0.089	0.061	0.040	0.026	0.017	0.011
12	0.391	0.378	0.342	0.290	0.232	0.176	0.128	0.089	0.060	0.040	0.026	0.016	0.010
13	0.391	0.378	0.343	0.291	0.233	0.177	0.128	0.089	0.060	0.039	0.025	0.016	0.010
14	0.392	0.379	0.343	0.292	0.234	0.177	0.128	0.089	0.060	0.039	0.025	0.015	0.010
15	0.392	0.380	0.344	0.292	0.234	0.177	0.128	0.089	0.059	0.038	0.024	0.015	0.009

Ordinates of t Distribution with v Degrees of Freedom, continued



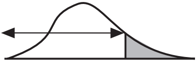
v	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
16	0.393	0.380	0.344	0.293	0.235	0.178	0.128	0.089	0.059	0.038	0.024	0.015	0.009
17	0.393	0.380	0.345	0.293	0.235	0.178	0.128	0.089	0.059	0.038	0.024	0.014	0.009
18	0.393	0.381	0.345	0.294	0.235	0.178	0.129	0.088	0.059	0.037	0.023	0.014	0.008
19	0.394	0.381	0.346	0.294	0.236	0.179	0.129	0.088	0.058	0.037	0.023	0.014	0.008
20	0.394	0.381	0.346	0.294	0.236	0.179	0.129	0.088	0.058	0.037	0.023	0.014	0.008
22	0.394	0.382	0.346	0.295	0.237	0.179	0.129	0.088	0.058	0.036	0.022	0.013	0.008
24	0.395	0.382	0.347	0.296	0.237	0.179	0.129	0.088	0.057	0.036	0.022	0.013	0.007
26	0.395	0.383	0.347	0.296	0.237	0.180	0.129	0.088	0.057	0.036	0.022	0.013	0.007
28	0.395	0.383	0.348	0.296	0.238	0.180	0.129	0.088	0.057	0.036	0.021	0.012	0.007
30	0.396	0.383	0.348	0.297	0.238	0.180	0.129	0.088	0.057	0.035	0.021	0.012	0.007
35	0.396	0.384	0.348	0.297	0.239	0.180	0.129	0.088	0.056	0.035	0.021	0.012	0.006
40	0.396	0.384	0.349	0.298	0.239	0.181	0.129	0.087	0.056	0.035	0.020	0.011	0.006
45	0.397	0.384	0.349	0.298	0.239	0.181	0.129	0.087	0.056	0.034	0.020	0.011	0.006
50	0.397	0.385	0.350	0.298	0.240	0.181	0.129	0.087	0.056	0.034	0.020	0.011	0.006
∞	0.399	0.387	0.352	0.301	0.242	0.183	0.130	0.086	0.054	0.032	0.018	0.009	0.004

χ^2 Distribution with v Degrees of Freedom



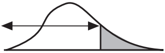
v	0.995	0.99	0.975	0.95	0.9	0.75	0.5	0.25	0.1	0.05	0.025	0.01	0.005	0.001
1	-	-	-	-	0.016	0.102	0.455	1.32	2.71	3.84	5.02	6.63	7.88	10.8
2	0.010	0.020	0.051	0.103	0.211	0.575	1.39	2.77	4.61	5.99	7.38	9.21	10.6	13.8
3	0.072	0.115	0.216	0.352	0.584	1.21	2.37	4.11	6.25	7.81	9.35	11.3	12.8	16.3
4	0.207	0.297	0.484	0.711	1.06	1.92	3.36	5.39	7.78	9.49	11.1	13.3	14.9	18.5
5	0.412	0.554	0.831	1.15	1.61	2.67	4.35	6.63	9.24	11.1	12.8	15.1	16.7	20.5
6	0.676	0.872	1.24	1.64	2.20	3.45	5.35	7.84	10.6	12.6	14.4	16.8	18.5	22.5
7	0.989	1.24	1.69	2.17	2.83	4.25	6.35	9.04	12.0	14.1	16.0	18.5	20.3	24.3
8	1.34	1.65	2.18	2.73	3.49	5.07	7.34	10.2	13.4	15.5	17.5	20.1	22.0	26.1
9	1.73	2.09	2.70	3.33	4.17	5.90	8.34	11.4	14.7	16.9	19.0	21.7	23.6	27.9
10	2.16	2.56	3.25	3.94	4.87	6.74	9.34	12.5	16.0	18.3	20.5	23.2	25.2	29.6
11	2.60	3.05	3.82	4.57	5.58	7.58	10.3	13.7	17.3	19.7	21.9	24.7	26.8	31.3
12	3.07	3.57	4.40	5.23	6.30	8.44	11.3	14.8	18.5	21.0	23.3	26.2	28.3	32.9
13	3.57	4.11	5.01	5.89	7.04	9.30	12.3	16.0	19.8	22.4	24.7	27.7	29.8	34.5
14	4.07	4.66	5.63	6.57	7.79	10.2	13.3	17.1	21.1	23.7	26.1	29.1	31.3	36.1
15	4.60	5.23	6.26	7.26	8.55	11.0	14.3	18.2	22.3	25.0	27.5	30.6	32.8	37.7

χ^2 Distribution with v Degrees of Freedom, continued



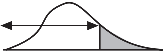
v	0.995	0.99	0.975	0.95	0.9	0.75	0.5	0.25	0.1	0.05	0.025	0.01	0.005	0.001
16	5.14	5.81	6.91	7.96	9.31	11.9	15.3	19.4	23.5	26.3	28.8	32.0	34.3	39.3
17	5.70	6.41	7.56	8.67	10.1	12.8	16.3	20.5	24.8	27.6	30.2	33.4	35.7	40.8
18	6.26	7.01	8.23	9.39	10.9	13.7	17.3	21.6	26.0	28.9	31.5	34.8	37.2	42.3
19	6.84	7.63	8.91	10.1	11.7	14.6	18.3	22.7	27.2	30.1	32.9	36.2	38.6	43.8
20	7.43	8.26	9.59	10.9	12.4	15.5	19.3	23.8	28.4	31.4	34.2	37.6	40.0	45.3
21	8.03	8.90	10.3	11.6	13.2	16.3	20.3	24.9	29.6	32.7	35.5	38.9	41.4	46.8
22	8.64	9.54	11.0	12.3	14.0	17.2	21.3	26.0	30.8	33.9	36.8	40.3	42.8	48.3
23	9.26	10.2	11.7	13.1	14.8	18.1	22.3	27.1	32.0	35.2	38.1	41.6	44.2	49.7
24	9.89	10.9	12.4	13.8	15.7	19.0	23.3	28.2	33.2	36.4	39.4	43.0	45.6	51.2
25	10.5	11.5	13.1	14.6	16.5	19.9	24.3	29.3	34.4	37.7	40.6	44.3	46.9	52.6
26	11.2	12.2	13.8	15.4	17.3	20.8	25.3	30.4	35.6	38.9	41.9	45.6	48.3	54.1
27	11.8	12.9	14.6	16.2	18.1	21.7	26.3	31.5	36.7	40.1	43.2	47.0	49.6	55.5
28	12.5	13.6	15.3	16.9	18.9	22.7	27.3	32.6	37.9	41.3	44.5	48.3	51.0	56.9
29	13.1	14.3	16.0	17.7	19.8	23.6	28.3	33.7	39.1	42.6	45.7	49.6	52.3	58.3
30	13.8	15.0	16.8	18.5	20.6	24.5	29.3	34.8	40.3	43.8	47.0	50.9	53.7	59.7

F Distribution: Upper 25% Points



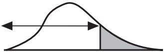
v_1 / v_2	1	2	3	4	5	6	7	8	9
1	5.83	7.50	8.20	8.58	8.82	8.98	9.10	9.19	9.26
2	2.57	3.00	3.15	3.23	3.28	3.31	3.34	3.35	3.37
3	2.02	2.28	2.36	2.39	2.41	2.42	2.43	2.44	2.44
4	1.81	2.00	2.05	2.06	2.07	2.08	2.08	2.08	2.08
5	1.69	1.85	1.88	1.89	1.89	1.89	1.89	1.89	1.89
6	1.62	1.76	1.78	1.79	1.79	1.78	1.78	1.78	1.77
7	1.57	1.70	1.72	1.72	1.71	1.71	1.70	1.70	1.69
8	1.54	1.66	1.67	1.66	1.66	1.65	1.64	1.64	1.63
9	1.51	1.62	1.63	1.63	1.62	1.61	1.60	1.60	1.59
10	1.49	1.60	1.60	1.59	1.59	1.58	1.57	1.56	1.56
11	1.47	1.58	1.58	1.57	1.56	1.55	1.54	1.53	1.53
12	1.46	1.56	1.56	1.55	1.54	1.53	1.52	1.51	1.51
13	1.45	1.55	1.55	1.53	1.52	1.51	1.50	1.49	1.49
14	1.44	1.53	1.53	1.52	1.51	1.50	1.49	1.48	1.47
15	1.43	1.52	1.52	1.51	1.49	1.48	1.47	1.46	1.46
16	1.42	1.51	1.51	1.50	1.48	1.47	1.46	1.45	1.44
17	1.42	1.51	1.50	1.49	1.47	1.46	1.45	1.44	1.43
18	1.41	1.50	1.49	1.48	1.46	1.45	1.44	1.43	1.42
19	1.41	1.49	1.49	1.47	1.46	1.44	1.43	1.42	1.41
20	1.40	1.49	1.48	1.47	1.45	1.44	1.43	1.42	1.41
21	1.40	1.48	1.48	1.46	1.44	1.43	1.42	1.41	1.40
22	1.40	1.48	1.47	1.45	1.44	1.42	1.41	1.40	1.39
23	1.39	1.47	1.47	1.45	1.43	1.42	1.41	1.40	1.39
24	1.39	1.47	1.46	1.44	1.43	1.41	1.40	1.39	1.38
25	1.39	1.47	1.46	1.44	1.42	1.41	1.40	1.39	1.38
26	1.38	1.46	1.45	1.44	1.42	1.41	1.39	1.38	1.37
27	1.38	1.46	1.45	1.43	1.42	1.40	1.39	1.38	1.37
28	1.38	1.46	1.45	1.43	1.41	1.40	1.39	1.38	1.37
29	1.38	1.45	1.45	1.43	1.41	1.40	1.38	1.37	1.36
30	1.38	1.45	1.44	1.42	1.41	1.39	1.38	1.37	1.36
40	1.36	1.44	1.42	1.40	1.39	1.37	1.36	1.35	1.34
60	1.35	1.42	1.41	1.38	1.37	1.35	1.33	1.32	1.31
120	1.34	1.40	1.39	1.37	1.35	1.33	1.31	1.30	1.29
∞	1.32	1.39	1.37	1.35	1.33	1.31	1.29	1.28	1.27

F Distribution: Upper 25% Points, continued



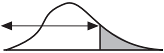
v_2 \ v_1	10	12	15	20	24	30	40	60	120	∞
1	9.32	9.41	9.49	9.58	9.63	9.67	9.71	9.76	9.80	9.85
2	3.38	3.39	3.41	3.43	3.43	3.44	3.45	3.46	3.47	3.48
3	2.44	2.45	2.46	2.46	2.46	2.47	2.47	2.47	2.47	2.47
4	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08
5	1.89	1.89	1.89	1.88	1.88	1.88	1.88	1.87	1.87	1.87
6	1.77	1.77	1.76	1.76	1.75	1.75	1.75	1.74	1.74	1.74
7	1.69	1.68	1.68	1.67	1.67	1.66	1.66	1.65	1.65	1.65
8	1.63	1.62	1.62	1.61	1.60	1.60	1.59	1.59	1.58	1.58
9	1.59	1.58	1.57	1.56	1.56	1.55	1.54	1.54	1.53	1.53
10	1.55	1.54	1.53	1.52	1.52	1.51	1.51	1.50	1.49	1.48
11	1.52	1.51	1.50	1.49	1.49	1.48	1.47	1.47	1.46	1.45
12	1.50	1.49	1.48	1.47	1.46	1.45	1.45	1.44	1.43	1.42
13	1.48	1.47	1.46	1.45	1.44	1.43	1.42	1.42	1.41	1.40
14	1.46	1.45	1.44	1.43	1.42	1.41	1.41	1.40	1.39	1.38
15	1.45	1.44	1.43	1.41	1.41	1.40	1.39	1.38	1.37	1.36
16	1.44	1.43	1.41	1.40	1.39	1.38	1.37	1.36	1.35	1.34
17	1.43	1.41	1.40	1.39	1.38	1.37	1.36	1.35	1.34	1.33
18	1.42	1.40	1.39	1.38	1.37	1.36	1.35	1.34	1.33	1.32
19	1.41	1.40	1.38	1.37	1.36	1.35	1.34	1.33	1.32	1.30
20	1.40	1.39	1.37	1.36	1.35	1.34	1.33	1.32	1.31	1.29
21	1.39	1.38	1.37	1.35	1.34	1.33	1.32	1.31	1.30	1.28
22	1.39	1.37	1.36	1.34	1.33	1.32	1.31	1.30	1.29	1.28
23	1.38	1.37	1.35	1.34	1.33	1.32	1.31	1.30	1.28	1.27
24	1.38	1.36	1.35	1.33	1.32	1.31	1.30	1.29	1.28	1.26
25	1.37	1.36	1.34	1.33	1.32	1.31	1.29	1.28	1.27	1.25
26	1.37	1.35	1.34	1.32	1.31	1.30	1.29	1.28	1.26	1.25
27	1.36	1.35	1.33	1.32	1.31	1.30	1.28	1.27	1.26	1.24
28	1.36	1.34	1.33	1.31	1.30	1.29	1.28	1.27	1.25	1.24
29	1.35	1.34	1.32	1.31	1.30	1.29	1.27	1.26	1.25	1.23
30	1.35	1.34	1.32	1.30	1.29	1.28	1.27	1.26	1.24	1.23
40	1.33	1.31	1.30	1.28	1.26	1.25	1.24	1.22	1.21	1.19
60	1.30	1.29	1.27	1.25	1.24	1.22	1.21	1.19	1.17	1.15
120	1.28	1.26	1.24	1.22	1.21	1.19	1.18	1.16	1.13	1.10
∞	1.25	1.24	1.22	1.19	1.18	1.16	1.14	1.12	1.08	1.00

F Distribution: Upper 10% Points



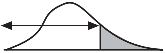
v_1 v_2	1	2	3	4	5	6	7	8	9
1	39.86	49.50	53.59	55.83	57.24	58.20	58.91	59.44	59.86
2	8.53	9.00	9.16	9.24	9.29	9.33	9.35	9.37	9.38
3	5.54	5.46	5.39	5.34	5.31	5.28	5.27	5.25	5.24
4	4.54	4.32	4.19	4.11	4.05	4.01	3.98	3.95	3.94
5	4.06	3.78	3.62	3.52	3.45	3.40	3.37	3.34	3.32
6	3.78	3.46	3.29	3.18	3.11	3.05	3.01	2.98	2.96
7	3.59	3.26	3.07	2.96	2.88	2.83	2.78	2.75	2.72
8	3.46	3.11	2.92	2.81	2.73	2.67	2.62	2.59	2.56
9	3.36	3.01	2.81	2.69	2.61	2.55	2.51	2.47	2.44
10	3.29	2.92	2.73	2.61	2.52	2.46	2.41	2.38	2.35
11	3.23	2.86	2.66	2.54	2.45	2.39	2.34	2.30	2.27
12	3.18	2.81	2.61	2.48	2.39	2.33	2.28	2.24	2.21
13	3.14	2.76	2.56	2.43	2.35	2.28	2.23	2.20	2.16
14	3.10	2.73	2.52	2.39	2.31	2.24	2.19	2.15	2.12
15	3.07	2.70	2.49	2.36	2.27	2.21	2.16	2.12	2.09
16	3.05	2.67	2.46	2.33	2.24	2.18	2.13	2.09	2.06
17	3.03	2.64	2.44	2.31	2.22	2.15	2.10	2.06	2.03
18	3.01	2.62	2.42	2.29	2.20	2.13	2.08	2.04	2.00
19	2.99	2.61	2.40	2.27	2.18	2.11	2.06	2.02	1.98
20	2.97	2.59	2.38	2.25	2.16	2.09	2.04	2.00	1.96
21	2.96	2.57	2.36	2.23	2.14	2.08	2.02	1.98	1.95
22	2.95	2.56	2.35	2.22	2.13	2.06	2.01	1.97	1.93
23	2.94	2.55	2.34	2.21	2.11	2.05	1.99	1.95	1.92
24	2.93	2.54	2.33	2.19	2.10	2.04	1.98	1.94	1.91
25	2.92	2.53	2.32	2.18	2.09	2.02	1.97	1.93	1.89
26	2.91	2.52	2.31	2.17	2.08	2.01	1.96	1.92	1.88
27	2.90	2.51	2.30	2.17	2.07	2.00	1.95	1.91	1.87
28	2.89	2.50	2.29	2.16	2.06	2.00	1.94	1.90	1.87
29	2.89	2.50	2.28	2.15	2.06	1.99	1.93	1.89	1.86
30	2.88	2.49	2.28	2.14	2.05	1.98	1.93	1.88	1.85
40	2.84	2.44	2.23	2.09	2.00	1.93	1.87	1.83	1.79
60	2.79	2.39	2.18	2.04	1.95	1.87	1.82	1.77	1.74
120	2.75	2.35	2.13	1.99	1.90	1.82	1.77	1.72	1.68
∞	2.71	2.30	2.08	1.94	1.85	1.77	1.72	1.67	1.63

F Distribution:
Upper 10% Points, continued



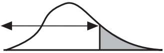
v_1 v_2	10	12	15	20	24	30	40	60	120	∞
1	60.19	60.71	61.22	61.74	62.00	62.26	62.53	62.79	63.06	63.33
2	9.39	9.41	9.42	9.44	9.45	9.46	9.47	9.47	9.48	9.49
3	5.23	5.22	5.20	5.18	5.18	5.17	5.16	5.15	5.14	5.13
4	3.92	3.90	3.87	3.84	3.83	3.82	3.80	3.79	3.78	3.76
5	3.30	3.27	3.24	3.21	3.19	3.17	3.16	3.14	3.12	3.10
6	2.94	2.90	2.87	2.84	2.82	2.80	2.78	2.76	2.74	2.72
7	2.70	2.67	2.63	2.59	2.58	2.56	2.54	2.51	2.49	2.47
8	2.54	2.50	2.46	2.42	2.40	2.38	2.36	2.34	2.32	2.29
9	2.42	2.38	2.34	2.30	2.28	2.25	2.23	2.21	2.18	2.16
10	2.32	2.28	2.24	2.20	2.18	2.16	2.13	2.11	2.08	2.06
11	2.25	2.21	2.17	2.12	2.10	2.08	2.05	2.03	2.00	1.97
12	2.19	2.15	2.10	2.06	2.04	2.01	1.99	1.96	1.93	1.90
13	2.14	2.10	2.05	2.01	1.98	1.96	1.93	1.90	1.88	1.85
14	2.10	2.05	2.01	1.96	1.94	1.91	1.89	1.86	1.83	1.80
15	2.06	2.02	1.97	1.92	1.90	1.87	1.85	1.82	1.79	1.76
16	2.03	1.99	1.94	1.89	1.87	1.84	1.81	1.78	1.75	1.72
17	2.00	1.96	1.91	1.86	1.84	1.81	1.78	1.75	1.72	1.69
18	1.98	1.93	1.89	1.84	1.81	1.78	1.75	1.72	1.69	1.66
19	1.96	1.91	1.86	1.81	1.79	1.76	1.73	1.70	1.67	1.63
20	1.94	1.89	1.84	1.79	1.77	1.74	1.71	1.68	1.64	1.61
21	1.92	1.87	1.83	1.78	1.75	1.72	1.69	1.66	1.62	1.59
22	1.90	1.86	1.81	1.76	1.73	1.70	1.67	1.64	1.60	1.57
23	1.89	1.84	1.80	1.74	1.72	1.69	1.66	1.62	1.59	1.55
24	1.88	1.83	1.78	1.73	1.70	1.67	1.64	1.61	1.57	1.53
25	1.87	1.82	1.77	1.72	1.69	1.66	1.63	1.59	1.56	1.52
26	1.86	1.81	1.76	1.71	1.68	1.65	1.61	1.58	1.54	1.50
27	1.85	1.80	1.75	1.70	1.67	1.64	1.60	1.57	1.53	1.49
28	1.84	1.79	1.74	1.69	1.66	1.63	1.59	1.56	1.52	1.48
29	1.83	1.78	1.73	1.68	1.65	1.62	1.58	1.55	1.51	1.47
30	1.82	1.77	1.72	1.67	1.64	1.61	1.57	1.54	1.50	1.46
40	1.76	1.71	1.66	1.61	1.57	1.54	1.51	1.47	1.42	1.38
60	1.71	1.66	1.60	1.54	1.51	1.48	1.44	1.40	1.35	1.29
120	1.65	1.60	1.55	1.48	1.45	1.41	1.37	1.32	1.26	1.19
∞	1.60	1.55	1.49	1.42	1.38	1.34	1.30	1.24	1.17	1.00

F Distribution: Upper 5% Points



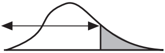
v_2 v_1	1	2	3	4	5	6	7	8	9
1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88

F Distribution: Upper 5% Points, continued



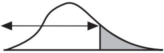
v_1 v_2	10	12	15	20	24	30	40	60	120	∞
1	241.9	243.9	245.9	248.0	249.1	250.1	251.1	252.2	253.3	254.3
2	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.78
23	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81	1.76
24	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
26	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
27	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
28	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
29	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
30	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
60	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35	1.25
∞	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

F Distribution:
Upper 1% Points



v_2 \ v_1	1	2	3	4	5	6	7	8	9
1	4052	4999.50	5403	5625	5764	5859	5928	5982	6022
2	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39
3	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35
4	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66
5	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16
6	13.75	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98
7	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72
8	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91
9	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35
10	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19
14	8.86	6.51	5.56	5.04	4.69	4.46	4.28	4.14	4.03
15	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78
17	8.40	6.11	5.18	4.67	4.34	4.10	3.93	3.79	3.68
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60
19	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40
22	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35
23	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26
25	7.77	5.57	4.68	4.18	3.85	3.63	3.46	3.32	3.22
26	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18
27	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15
28	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12
29	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72
120	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.56
∞	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41

F Distribution: Upper 1% Points, continued



v_2 \ v_1	10	12	15	20	24	30	40	60	120	∞
1	6056	6106	6157	6209	6235	6261	6287	6313	6339	6366
2	99.40	99.42	99.43	99.45	99.46	99.47	99.47	99.48	99.49	99.50
3	27.23	27.05	26.87	26.69	26.60	26.50	26.41	26.32	26.22	26.13
4	14.55	14.37	14.20	14.02	13.93	13.84	13.75	13.65	13.56	13.46
5	10.05	9.89	9.72	9.55	9.47	9.38	9.29	9.20	9.11	9.02
6	7.87	7.72	7.56	7.40	7.31	7.23	7.14	7.06	6.97	6.88
7	6.62	6.47	6.31	6.16	6.07	5.99	5.91	5.82	5.74	5.65
8	5.81	5.67	5.52	5.36	5.28	5.20	5.12	5.03	4.95	4.86
9	5.26	5.11	4.96	4.81	4.73	4.65	4.57	4.48	4.40	4.31
10	4.85	4.71	4.56	4.41	4.33	4.25	4.17	4.08	4.00	3.91
11	4.54	4.40	4.25	4.10	4.02	3.94	3.86	3.78	3.69	3.60
12	4.30	4.16	4.01	3.86	3.78	3.70	3.62	3.54	3.45	3.36
13	4.10	3.96	3.82	3.66	3.59	3.51	3.43	3.34	3.25	3.17
14	3.94	3.80	3.66	3.51	3.43	3.35	3.27	3.18	3.09	3.00
15	3.80	3.67	3.52	3.37	3.29	3.21	3.13	3.05	2.96	2.87
16	3.69	3.55	3.41	3.26	3.18	3.10	3.02	2.93	2.84	2.75
17	3.59	3.46	3.31	3.16	3.08	3.00	2.92	2.83	2.75	2.65
18	3.51	3.37	3.23	3.08	3.00	2.92	2.84	2.75	2.66	2.57
19	3.43	3.30	3.15	3.00	2.92	2.84	2.76	2.67	2.58	2.49
20	3.37	3.23	3.09	2.94	2.86	2.78	2.69	2.61	2.52	2.42
21	3.31	3.17	3.03	2.88	2.80	2.72	2.64	2.55	2.46	2.36
22	3.26	3.12	2.98	2.83	2.75	2.67	2.58	2.50	2.40	2.31
23	3.21	3.07	2.93	2.78	2.70	2.62	2.54	2.45	2.35	2.26
24	3.17	3.03	2.89	2.74	2.66	2.58	2.49	2.40	2.31	2.21
25	3.13	2.99	2.85	2.70	2.62	2.54	2.45	2.36	2.27	2.17
26	3.09	2.96	2.81	2.66	2.58	2.50	2.42	2.33	2.23	2.13
27	3.06	2.93	2.78	2.63	2.55	2.47	2.38	2.29	2.20	2.10
28	3.03	2.90	2.75	2.60	2.52	2.44	2.35	2.26	2.17	2.06
29	3.00	2.87	2.73	2.57	2.49	2.41	2.33	2.23	2.14	2.03
30	2.98	2.84	2.70	2.55	2.47	2.39	2.30	2.21	2.11	2.01
40	2.80	2.66	2.52	2.37	2.29	2.20	2.11	2.02	1.92	1.80
60	2.63	2.50	2.35	2.20	2.12	2.03	1.94	1.84	1.73	1.60
120	2.47	2.34	2.19	2.03	1.95	1.86	1.76	1.66	1.53	1.38
∞	2.32	2.18	2.04	1.88	1.79	1.70	1.59	1.47	1.32	1.00

Sigma
Conversion Chart

Long-term Yield	Long-term Sigma	Short-term Sigma	Defects per Million
99.99966%	4.5	6.0	3.4
99.9995%	4.4	5.9	5
99.9992%	4.3	5.8	8
99.9990%	4.2	5.7	10
99.9980%	4.1	5.6	20
99.9970%	4.0	5.5	30
99.9960%	3.9	5.4	40
99.9930%	3.8	5.3	70
99.9900%	3.7	5.2	100
99.9850%	3.6	5.1	150
99.9770%	3.5	5.0	230
99.9670%	3.4	4.9	330
99.9520%	3.3	4.8	480
99.9320%	3.2	4.7	680
99.9040%	3.1	4.6	960
99.8650%	3.0	4.5	1,350
99.8140%	2.9	4.4	1,860
99.7450%	2.8	4.3	2,550
99.6540%	2.7	4.2	3,460
99.5340%	2.6	4.1	4,660
99.3790%	2.5	4.0	6,210
99.1810%	2.4	3.9	8,190
98.930%	2.3	3.8	10,700
98.610%	2.2	3.7	13,900
98.220%	2.1	3.6	17,800
97.730%	2.0	3.5	22,700
97.130%	1.9	3.4	28,700
96.410%	1.8	3.3	35,900
95.540%	1.7	3.2	44,600
94.520%	1.6	3.1	54,800
93.320%	1.5	3.0	66,800
91.920%	1.4	2.9	80,800
90.320%	1.3	2.8	96,800
88.50%	1.2	2.7	115,000
86.50%	1.1	2.6	135,000
84.20%	1.0	2.5	158,000
81.60%	0.9	2.4	184,000
78.80%	0.8	2.3	212,000
75.80%	0.7	2.2	242,000
72.60%	0.6	2.1	274,000
69.20%	0.5	2.0	308,000
65.60%	0.4	1.9	344,000
61.80%	0.3	1.8	382,000
58.00%	0.2	1.7	420,000
54.00%	0.1	1.6	460,000
50.00%	0.0	1.5	500,000
46.00%	-0.1	1.4	540,000
42.00%	-0.2	1.3	580,000
38.00%	-0.3	1.2	620,000
34.00%	-0.4	1.1	660,000
31.00%	-0.5	1.0	690,000
27.00%	-0.6	0.9	730,000
24.00%	-0.7	0.8	760,000

Note: The 1.5 sigma shift is included in this chart.

Index

GOAL QPC

Improving the Way Organizations Run

GOAL QPC

IMPROVING THE WAY ORGANIZATIONS RUN

The TEAM MEMORY JOGGER™

A Pocket Guide for Team Members

A GOAL/QPC-Joiner®
Publication

GOAL QPC

IMPROVING THE WAY ORGANIZATIONS RUN

THE TEAM MEMORY JOGGER™

A pocket guide for team members

First Edition

GOAL/QPC and Oriel Incorporated

The Team Memory Jogger™

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Printed in the United States of America

First Edition
10 9 8 7 6 5

Dear Team Member,

Since the early 1980s, Oriel Incorporated and GOAL/QPC have both been leaders in helping organizations continuously improve their business performance.

We both have publications that organizations have found helpful in creating a more productive workplace through techniques such as process improvement, problem solving, and effective teamwork. The Memory Jogger™ *has helped over 5 million customers around the world make fuller use of graphical and statistical methods.* The Team Handbook*, with more than 700,000 copies in circulation, has helped thousands of teams achieve significant progress.*

*We have now joined together to create a convenient, practical guide for team members—*The Team Memory Jogger™. *Here you'll find additional inspiration, information, and tips you need for even more productive teamwork. Please let us know what you think.*

Sincerely,

Patricia

Michael Brassard

Brian L. Joiner

Acknowledgments

We thank the following people for their contributions to this book.

Mike Adams, *Opryland USA*

Carol Anderson, *Park Nicollet Medical Center*

Davis Balestracci, *Park Nicollet Medical Center*

Daniel Brown, *Busch Entertainment Corp.*

Elaine Engelke, *Public Service Commission*

Bob Faneuff, *Air Force Quality Institute*

Bill Farrell, *Army & Air Force Exchange*

Paul Grunzke, *Air Force Quality Institute*

Kathleen Holm, *Land O'Lakes*

Brian Joiner, *Joiner Associates Inc.*

Kevin Kelleher, *Oriel Incoporated*

Donna Koenig, *Land O'Lakes*

Robyn Kuttler, *Inova Health Systems*

John Lowe, *Sea World of Ohio*

Kimberly Maginnis, *Urgent Medical Care*

Ralph Miller, *S&B Engineering*

Keith Nowack, *Atlantic Steel Corporation*

Antonio Rodriguez, *Department of the Navy*

Dan Sage, *Public Service Commission*

Don Walker, *Toshiba USA*

Table of Contents

Chapter 1: Preparing to Be an Effective Team Member

Chapter 2: Getting a Good Start

Chapter 3: Getting Work Done in Teams

Chapter 4: Knowing When and How to End

Chapter 5: Problems Within the Team

INTRODUCTION

Being part of a team

By becoming part of a team, you have a chance to help your organization tap into a tremendous reservoir of talent, knowledge, and creativity… YOU! You also have a chance to take advantage of a great learning opportunity.

- You can learn more about your job and the people you work with, as well as your organization and its customers.
- You also have a chance to learn and practice useful work skills.

But working on a team also has challenges.

- For one thing, teams are often brought together to deal with complex or long-standing business problems. So the work itself may not be easy. Periods of rapid progress will likely alternate with periods of frustrating setbacks.
- In addition, coordinating the efforts, schedules, and interests of many people is not simple.

- While some people work on teams full time, most have to juggle team work with their ongoing job responsibilities.
- Though it is exciting to be with people who have different ideas and perspectives, it can also lead to conflict and frustration.

The Team Memory Jogger™ can help you take advantage of the rewards offered by team membership and work through the challenges.

How this book can help

This book contains guidelines that can increase your chances of having a good team experience. It is intended to serve as a quick reminder of things you have already learned through training or experience on the job. The topics are:

- **Preparing to be an effective team member** (Chapter 1, pp. 5-28)
  A team can only be as effective as its individual members. This chapter covers basic skills that can help you contribute to your team.
- **Getting a good start** (Chapter 2, pp. 29-60)
  Many teams get well into an effort without fully understanding why they exist or

consciously deciding how they want to work. This chapter pulls together key issues that teams should work on right up front.

- **Doing work as a team** (Chapter 3, pp. 61-110)
  Many of the basic work skills you already have are useful for working on a team as well. This chapter provides reminders on how to use those skills when working with other people.

- **Knowing when and how to end** (Chapter 4, pp. 111-134)
  It is easy for team members to get so wrapped up in a particular effort that they ignore the signals that indicate it is time to stop and move on to something else. This chapter reviews steps the team can take to end successfully.

- **Problems within the team** (Chapter 5, pp. 135-160)
  All teams run into problems now and then. There are times when people get along and work flows smoothly, and times when people argue and progress stops. Learning how to work through the problem times is critical for having an effective team. While some team problems are quite serious and require help

from outside experts, there are steps that team members can take to help their teams. This chapter provides troubleshooting tips on how to work through team problems

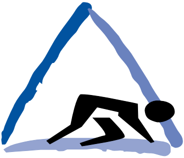
Who is this book for?

This book is targeted at team members—the people who carry out the work of the team. Each topic is examined from the viewpoint of what a team member can do, not what the team leader or a manager should do. The basic information here is relevant to all kinds of teams—project teams, process improvement teams, self-directed or intact work teams, task forces, and so on.

How to use this book

- If you have a specific topic you're interested in, check the Index or Table of Contents.
- To get an overview of what's in each chapter, go to the chapter title pages (they all have a blue edge). Turn the page and you'll see a checklist to help you determine which topic might be useful to you.

CHAPTER 1



PREPARING TO BE AN EFFECTIVE TEAM MEMBER

Quick Finder

Personal Skills Checklist

Working as part of a team is different than doing a job by yourself. It requires specific skills, many of which you may already have. Take a minute to ask yourself how ready you are to be part of a team.

For example, how often do you…	Rarely	Sometimes	Often
Take responsibility for the success of the team (p. 8)	❍	❍	❍
Follow through on commitments (p.10)	❍	❍	❍
Contribute to discussions (p. 12)	❍	❍	❍
Actively listen to others (p. 15)	❍	❍	❍
Get your **message across** clearly (p. 19)	❍	❍	❍
Give **useful feedback** (p. 21)	❍	❍	❍
Accept feedback easily (p. 26)	❍	❍	❍

You and Your Team

Much of this book talks about things that you and your teammates have to work on together—like creating plans, making changes, solving problems.

But the real foundation of a strong team is strong members: People committed to making the team a success. People who know how to get their ideas across. People who can listen to others and who are open to new ideas. People who are willing to expose and deal with problems rather than hide them under the rug.

Nobody reaches this stage overnight. And no one ever does all these things all the time. But with practice, we can all become more effective team members.

Tips on using this chapter

- Review the checklist on the previous page and evaluate how well you practice these skills.
- Read about the areas you'd like to improve.
- Later on, skim through this chapter periodically to remind yourself of key points.

Taking Responsibility

Why it's important

One of the key things to share on a team is the responsibility for making it a success. Having all team members be responsible is important because…

- Teams often get involved in work that is important to the organization's business success.
- Doing this work well requires the commitment and dedication of all team members.
- Each team member has a unique perspective to offer.
    - Often the best ideas are left unsaid. Your ideas may be critical to helping the team find a workable solution.

What you can do

- **Commit yourself to being part of the team's success**
    - – Focus on the team's purpose.
    - – Help the team get its work done.
    - – Speak out when you think the team is going in a wrong direction.
    - – Remember that you are working with other people, not against them.
- **Help your team build a common understanding of the issues it faces**
    - – Speak up when you have ideas to share.
    - – Listen to others and let them influence you; build on ideas already offered.
    - – Express your support of others' ideas.
- **Be responsible for what you say and do**
    - – Keep your commitments to the team. (See p. 10)
    - – Be aware of how your words and actions affect your team. (See pp. 12 and 21)

Following Through on Commitments

Why it's important

Other team members depend on you to get your work done so they can get their work done. Completing assignments on time helps your team make progress and maintain momentum.

➤ **TIP** *Ask your teammates, team leader, or manager for help if you have trouble following through on commitments. See if your workload can be temporarily adjusted or if others could help you complete specific tasks.*

What you can do

- **Make your best effort to keep your commitments**
  - Find some way to remind yourself of deadlines and commitments. For example, make notes in a calendar or carry a small pocket-sized notebook.
  - If you cannot follow through on a particular task, let people know as soon as possible so other arrangements can be made.

- **Consider your current commitments and priorities before agreeing to take on more work**
  - Discuss your priorities with your supervisor, manager, or team leader.
  - Though it can be hard to do, saying “no” is more helpful to the team than promising to do something you cannot do.

Contributing to Discussions

Why it's important

The power of teams lies in having people share their ideas and experiences. Much of that sharing happens through discussions. The better your discussion skills, the more you will be able to help your team. These discussion skills are useful in many situations. You'll find them referred to throughout this book.

What you can do

- **Contribute your ideas and suggestions to discussions**
- **Listen closely to others**
  - This is a very important skill. (See pp. 15 to 18)
- **Help *manage* your team's discussions**
  - Help keep the discussions on track.
  - Help involve everyone.

Discussion skills checklist

The list below and on the next page gives examples of useful discussion skills. How many of them do you practice regularly?

❍ **I give reasons for my opinions**
"I disagree. I get more complaints from customers about packaging than about delivery time."

❍ **I ask others to explain reasons behind their opinions**
"Olivia, could you tell me more about why you think we need a new supplier?"

❍ **I help involve other people by asking for their opinions or ideas**
"I'd like to hear what Mary and Tom have to say about what goes on in the production line."

❍ **I try to bring the group back on track when discussions wander**
"I agree that figuring out the accounting codes is important, but can we list it as a topic for our next meeting and get back to today's agenda item?"

Discussion skills checklist, cont.

❍ **I pull together and summarize ideas**
"It sounds like all the problems are related to faulty magnetic strips on the new ATM cards. Is that right?"

❍ **I suggest methods the group can use to work on issues**
"I'm having a hard time keeping track of all the ideas being raised. Why don't we all take a minute to silently write down our ideas and then go around the table and hear what everyone has to say?"

❍ **I help the group check for agreement**
"Do we all agree that we should focus our attention on incorrect entries?"

❍ **I try to find areas of agreement in conflicting points of view**
"Michael and Barb, am I right in thinking that you both agree the current computer programs can't do what we need them to do, but that you each have different ideas about what new program we should switch to?"

Listening to Understand

Why it's important

The success of a team often depends on how often and how easily team members reach a common understanding of issues. Listening to understand what your teammates are trying to say is at the very heart of teamwork.

Listening is also an important sign of respect. It encourages your teammates to participate in the team and shows that you value their opinions and ideas.

What you can do

- **Give others your full attention**
  - Resist distractions. Keep focused on the speaker even when other things are going on in the room.
- **Be open to others' ideas**
  - Concentrate on understanding the speaker.
  - Accept that the speaker's views, opinions, and values may be different than yours—and might be better!

- **Demonstrate that you are listening**
  - Ask questions.
  - Check your understanding.
    "If I hear you right, Julio, you're saying you object to the changes because you think our time estimates are unrealistic. Is that right?"
- **Combine the ideas you heard with other ideas raised by the team**
  - Listening is more than just hearing the words someone says. Think about what the person is saying and see if you can relate it to your own ideas or those of your other teammates.

➤ **TIP** *Take notes. Try to capture the key words as someone else speaks. Don't worry about trying to get every word down.*

➤ **TIP** *Pay attention to a person's body language. It can help you interpret their words.*

Examples of listening skills

The next two pages provide checklists to help you judge how well you listen. Use them to help you identify areas you may need to improve.

Listening skills checklist

You may think you are listening to your teammates, but are you really? Use the following lists to identify areas you may need to work on.

Signs you ARE listening effectively	Rarely	Sometimes	Often
I restate what I think I heard other people say as a way to check for understanding	○	○	○
I give my undivided attention to the speaker	○	○	○
I listen with an open mind	○	○	○
I ask people to slow down if they are speaking too fast	○	○	○
I ask people to explain words or terms that I don't understand	○	○	○

Listening skills checklist, cont.

The checklist on this page can serve as a quick reminder of signs that you are not listening to your teammates.

Signs you are NOT listening	Rarely	Sometimes	Often
I think about what to say next instead of listening	○	○	○
I bring up ideas already suggested	○	○	○
I ask questions that have already been answered	○	○	○
I lose track of a discussion or decisions the team made	○	○	○
I'm sure I know what people are going to say before they say it	○	○	○
I interrupt other speakers	○	○	○

Getting Your Message Across Clearly

Why it's important

As a team member, you have a responsibility to share your knowledge and experience with the rest of the team. To make sure the full team understands your point of view, it's important for you to get your message across clearly.

What you can do

- **Be clear about what messages or points you want to make**
  - Before you speak, try to be clear in your own mind how your points relate to the topic under discussion.
- **Speak in ways that help people understand what you want to say**
  - See the following page for some hints.
- **Be prepared to support your ideas with examples, information, data, or pictures**

Building your communication skills

Speaking in a team meeting can be tough. Fortunately, it gets easier with practice! Here are some tips to help you get started:

- ***Speak loudly** enough so others can hear.*
- ***Keep focused** on key points. Don’t ramble.*
- ***Explain special or unusual terms** you use; avoid jargon when you can.*
- ***Avoid sarcasm** or “put downs.”*
- *Show how your message **ties into the topic** being discussed.*
- *Practice making **eye contact** with the people in the room.*
  - *This may be hard, but eye contact helps listeners feel more connected to you. It also helps you know if people are lost.*
- ***Try drawing a simple sketch** of what you have in mind. Many people understand pictures better than words.*

➤ **TIP** *Jot down key ideas between team meetings and discuss them with someone else. This helps you clarify your own ideas.*

Giving Useful Feedback

Why it's important

Giving feedback means sharing your reactions with a person regarding what they've said or done. Giving feedback…

- Shows that you care about your relationship with the other person.
- Gives you and the other person a chance to work out differences so your team can work more effectively.

What you can do

- **Notice when someone else is doing something particularly helpful to the team**
- **Notice when someone else's behavior or language is making you uncomfortable or disrupting the team**
- **Give these people *useful* feedback**
  - "Useful" means the other person will understand and be able to act on the information you give them. (See pp. 22 to 25)

Building your feedback skills

- ***Review the actions and decisions*** *that led up to the moment.*
- *Give feedback* ***sooner rather than later****.*
- ***Choose an appropriate time and place****.*
  - *Be selective about when you share negative reactions in particular. Do it one-on-one and when you will be around to follow up with the person. Hit-and-run feedback is not fair.*
- *Start by* ***describing the context.***
  "I'd like to talk to you about what happened in the meeting today."
- *Describe your* ***reactions and reasons****.*
  "I was distracted by your side conversation and couldn't follow what others were saying."
- ***Ask for the change*** *you'd like to see.*
  "You often have good points to make and I'd like it if you would share them with the whole group rather than talking over other people."
- ***Allow time*** *for the other person to respond.*

Examples of useful feedback

The following pages cover some basic tips on giving feedback. The examples focus on typical feedback statements and how they can be made more useful.

Dealing with the hard stuff

Nobody enjoys telling someone you want them to change their behavior. It's hard to deal face-to-face with someone you strongly disagree with or whose behavior upsets you.

- *Review the guidelines here before you meet with the other person.*
- *Plan out or rehearse what you want to say; jot down notes.*
- *Treat the other person with the respect you would like to be shown.*
- *Ask the other person to meet you where you won't be overheard or interrupted.*
- *Remember that you can only control what* you *say and what* you *do. You cannot control the other person.*

Examples of useful feedback

Describe the specific behavior or incident—don't use labels or make judgments

Say this	instead of this
"When you don't do your assignments…"	"When you're irresponsible…"
"It bothers me that you don't let the team have more say in decisions."	"When you act like a little dictator…"
"When you don't speak up, I'm not sure what you're thinking."	"It's obvious you don't care about the team because you don't speak up in our meetings."

Don't exaggerate

Say this	instead of this
"I'm impressed with your work on the customer hotline the past two days."	"Your work is always better than anyone else's."

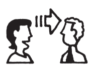
Examples of useful feedback, cont.

Speak for yourself, not for anyone else

Say this	instead of this
"I am uncomfortable when you and Vic argue at the meetings."	"Everybody hates it when you and Vic argue."
"I liked the way you organized the management report."	"The team liked the management report."
"I was distracted in the meeting by your jokes."	"Pat told me you were telling a lot of jokes in the meeting."

Talk first about yourself, not about the other person

Say this	instead of this
"I'm having trouble knowing how to keep the team on track when…"	"You keep getting us off track."



Accepting Feedback

Why it's important

Just as giving feedback helps other people know how they are affecting you, accepting feedback helps you know how you are affecting others.

What you can do

- **Accept the feedback people give you**
- **Consider this feedback carefully**
  - What are you doing well that you should continue doing?
  - What are you doing that might be interfering with your team's effectiveness?

➤ **TIP** *Accepting feedback does NOT mean you automatically agree with the other person or that you will change your behavior. It only means you will make an effort to understand the other person's concerns.*

Building your skill at accepting feedback

Accepting feedback is just as important as giving feedback. Here are some tips.

- ***Breathe deeply****. This can help you relax.*
- ***Listen carefully.***
- ***Make sure you understand what the other person is saying.***
  - *You need to understand what the other person wants you to change.*
  - *Ask for examples.*
    "Can you describe what I do or say that seems aggressive to you?"
- ***Acknowledge valid points even if you don't agree with the other person's interpretation.*** *For example, you can acknowledge that you have been late without agreeing that you are irresponsible.*
- ***Acknowledge the feedback but take time to sort out what you heard.***
  - *A simple "Thank you" is all that is needed right away.*
  - *Ask for time to think about what you heard. If possible, schedule a time to get back together with the person.*

CHAPTER 1: ACTION TIPS

Here are some ideas about taking action on the personal skills described in Chapter 1.

- *Don't think you have to become an expert in all these skills overnight. Work on them gradually. Focus on one or two at a time.*
- *Practice the feedback skills at home or elsewhere in your personal life.*
- *Find out what training your company already offers that you are eligible to attend.*
  - *Check with your team leader, supervisor, manager, or training department.*
- *If there is someone in your company who is good at the skill you want to learn, ask them for advice. How did they develop their skills? Can they recommend ways to learn more?*
- *Check if your company has books or videos on the subjects that interest you.*

CHAPTER 2

GETTING A GOOD START

Quick Finder

Start-Up Checklist

Use the following checklist to identify areas your team may need to work on as it gets started. Even if you are not the team leader, you can speak up if you think your team has skipped any of these important steps.

	Yes	No
We have agreed on a **purpose** and written a purpose statement (p. 32)	○	○
We have identified the people inside and outside the company who can influence or who will be affected by our work (the **stakeholders**) (p. 37)	○	○
We have identified the **limits** and **expectations** for the team's work (p. 44)	○	○
We have agreed on the **team roles** (who will have which responsibilities) (p. 48)	○	○
We have agreed on **ground rules** (p. 53)	○	○
We have decided on **logistics** for when and where we will meet (p. 58)	○	○

Keys to Getting a Good Start

What happens before a team gets started and in the first few meetings often determines whether it will be a success. You can help your team get off to a good start by taking an active role in getting everyone to discuss how they want the team to operate.

Tips on using this chapter

- Review the checklist on the previous page as a quick reminder of issues your team should address.
- If you checked any items "No," review those parts of this chapter. Make sure you understand the issues. Review the tips given for what you personally can do.
- In a team meeting or one-on-one with your team leader, ask that these issues be discussed by the whole team.

Agreeing on a Team Purpose

Why it's important to your team

Reaching a common understanding of the team's purpose gives a team a firm foundation.

- It helps everyone understand what the team is supposed to do and why.
    - If people on the team have different goals in mind, the team can be pulled in many directions at once. This can interfere with the team's work, and some people may become dissatisfied.
- It helps your team define success.
- It can help you establish boundaries for what is and is not included in the team's work. (See p. 44)
    - Knowing what your team is supposed to do helps you understand what it is not supposed to do. For example, your team may have been created to implement a solution, not to come up with alternative solutions.

Why it's important to you

Having a clear team purpose also helps you…

- Know what impact the team's work may have on your job.
- Understand the importance of what the team is trying to do.
- Communicate more easily with your co-workers about what the team is doing.
- Focus your thinking and creativity.

➤ **TIP** *Make your team's purpose **visible**. For example, put a sentence about it on your agendas or post it at each team meeting.*

What you can do

- **Find out what your team's purpose is**
  - Ask to see any memos, documents, and data that describe what issues or areas your team should be working on.
  - Support efforts to create a purpose statement.
- **Make sure you understand what that purpose means**
  - Ask your team to discuss the purpose at a team meeting.
- **Use the team's purpose to guide your actions**
  - If you think the team is straying from its purpose, speak up.

Examples of developing purpose statements

The next two pages show the basic ingredients of good purpose statements and some brief examples.

What makes a good purpose statement?

A good purpose statement…

- ***Describes a specific focus** for your team*
  - *It should distinguish your team's work from that of other teams.*
  - *It should let your team understand what work falls within its scope.*
- ***Describes realistic goals***
  - *Goals and targets can help the team make decisions about the level of effort needed. It makes a difference whether the desired improvement is 10% or 50%.*
  - *Goals and targets often come from management. However, your team can still use data on customer needs and business needs to judge how much improvement is needed.*
- ***Is clear, understandable, and brief***
  - *A short statement that everyone can remember is best.*
- ***Is energizing and inspirational***

Examples of purpose statements

The following examples of purpose statements are short enough to be written at the top of agendas or posted in a meeting room. Additional detail should be included in the team's records.

- Provide accurate accounting of employee hours for all Northwest Region facilities
- Fill vacant positions with qualified people within one month of job posting
- Reduce the level of iron contaminate from the current level of 29 ppm to no more than 5 ppm within one year
- Agree on and document the steps for handling accounts with payments more than 30 days past due
- Double the number of new customers from 20 per month to 40 per month while maintaining all current customers

Identifying Stakeholders

Why it's important to your team

Your team's work will affect and be affected by people and groups inside and outside your organization—your **stakeholders.** Knowing who these people are and involving them as you go helps you…

- Understand what is important about your work.
- Identify better solutions to problems and create more buy-in of solutions your team proposes.
- Plan how to include them when your team will be making decisions that affect them.
- Avoid pitfalls and identify limits.
- Know where to get information that will influence your team's work.

Why it's important to you

Understanding stakeholder needs can help you understand how you can best contribute to your team. Some stakeholders, for instance, will be people you work with every day. The better you can communicate with them about issues that concern them, the more you can help your team's work go smoothly.

What you can do

- **Help your team identify its stakeholders and understand their needs and concerns**
    - Think about the scope of your team's effort and who might be affected by its work.
    - Think about groups or people who can affect your work, both inside and outside the organization.
    - Involve these people as appropriate.
- **Use your knowledge of their needs to guide your actions, priorities, and decisions**

➤ **TIP** *Don't overreact to what any single group of stakeholders tells you. Some of their needs may conflict with your team's purpose or with your boundaries or limits. Check any conflicts with management.*

Examples of stakeholders

The following pages describe four common stakeholder groups. Use these examples to spark your own thinking about your team's stakeholders.

➤ **TIP** *Think broadly about who your stakeholders are. People in other departments, for example, might be able to benefit from your team's work. Groups outside your organization—such as regulatory agencies—may influence what options your team can pursue.*

Managers

What they often care about	Tips for dealing with these stakeholders
• Business results • Customer satisfaction • Schedules • Budgets • Use of resources • Forecasting	• In general, the team leader is responsible for communicating with management about the team's needs and progress. • However, every team member can take advantage of opportunities that come along to keep in touch with their direct supervisor or manager.

Customers

What they often care about	Tips for dealing with these stakeholders
• Quality • Value • Delivery time or turnaround time • Cost • What needs are met by features of your products or services	• Customers are often your most important stakeholders. • See if your organization has existing information about these customers and their needs. • If possible, invite some customers to a team meeting. Better still, visit a customer site to find out in detail how they use your product or service. What do they especially like or not like?

Examples of stakeholders, cont.

Coworkers	
What they often care about	**Tips for dealing with these stakeholders**
• How they will be involved in or affected by the team's work • What information or support they will be expected to give the team • If they will have to change the way they work	• Communicate regularly with people not on the team. • Explain the what and why of your team's work to them. • Listen to their needs and concerns. • If your team duties mean they have to do extra work, ask your manager if there is some way to ease the burden.

➤ **TIP** *Some organizations encourage people to think of coworkers as "customers." However, the needs of the customers who purchase your products or services are most important.*

Suppliers	
What they often care about	**Tips for dealing with these stakeholders**
• What they are expected to provide to you • If you are getting your needs met • If you will still want to do business with them • If they will be expected to make changes	• Be clear about what you expect of suppliers. • Most suppliers will be eager to work with you if changes are needed. • If possible, invite a key supplier or two to a team meeting or arrange a visit to their site.

Identifying Limits and Expectations

Why it's important to your team

No team gets a blank check to do as much work as it wants anywhere in the organization. Knowing what limits there are and what expectations others have can help your team…

- Meet your organization's business goals.
- Address all the important aspects of the work.
- Minimize conflict or confusion.
- Balance the expectations of different stakeholders.

Why it's important to you

- Some aspect of the limits on the team will affect you personally.
  - For instance, there will probably be limits on how much time you can devote to the team's work.

What you can do

- **Find out what the limits and expectations are for your team**
  - Ask your team leader to discuss these issues at a team meeting.
- **Understand these limits and expectations**
- **Use your knowledge of limits and expectations to guide your actions and decisions**
  - Before taking action or making important decisions, do a quick check to make sure your team isn't exceeding its limits.
  - Periodically ask your team leader or manager if the expectations, purpose, or limits have changed.

Examples of limits and expectations

The following pages show some typical categories of limits and specific examples within these categories.

Examples of limits and expectations

The list below and on the next page gives examples of limits placed on a team.

- **Money/budget**
  There is a budget of $500 for completing the first phase of the work.
- **Time/deadlines**
  This project must be completed by May 30th.
- **Workloads and priorities**
  Team members are expected to put in no more than five hours a week on the team's work.
- **People on the team**
  The project team will have one design engineer, one production supervisor, and two maintenance personnel on it. Other people can be called in as needed.
- **Other people who can be used as resources**
  Curtis H. will be the technical advisor for the team.
- **Training**
  The team can get training only if it can be done in-house and takes no more than six hours.

Examples of limits and expectations, cont.

- **Decision-making authority**
  The team can implement decisions that require less than a $100 investment, provided all potentially affected areas are contacted ahead of time to make sure there are no negative side effects.

- **Access to information**
  The team has open access to all data currently on file. Requests for additional customer data should be forwarded to the sales and marketing departments.

- **Process boundaries**
  Study the order entry process from the time a customer calls until there is a printed bill of lading.

- **Products or areas that will and won't be included**
  The credit vouchers team will look at all vouchers that arise from product returns. It will not study credit vouchers that result from sales incentives.

Defining Team Roles

Why it's important to your team

For any team to function well, its members need to know what is expected of them.

- When people know what their roles are, individuals know what jobs they should do and what jobs will be done by others.
- This helps avoid problems such as no one doing key tasks or one person trying to do everything.

Why it's important to you

Knowing how the work of your team is divided among team members helps you…

- Decide who to communicate with when you have questions or input.
- Understand and keep your commitments.

What you can do

- **Find out how your team is dividing up its work**
- **Understand what is expected of you personally**
  - For example, should you be volunteering to take notes in meetings or to collect data between meetings? Will you be expected to facilitate a meeting?
- **Use your knowledge of roles and responsibilities to meet your obligations to the team**
  - Volunteer for tasks when appropriate.

Formal and Informal Roles

The next three pages describe three formal team roles: team leader, team member, and facilitator/coach. However, many tasks on a team are done informally. People just volunteer to do a particular kind of work such as collecting data, planning a particular effort, or keeping notes. Usually it works best for your team to be flexible in how it divides up its work.

Examples of team roles

Team leader

A team leader guides and manages the day-to-day activity of the team. This involves…

- Educating team members about the team's purpose, limits, etc.
- Tracking the team's goals and achievements
- Anticipating and responding to changes in timing, schedules, workloads, and problems
- Helping team members develop their skills
- Communicating with management about the team's progress and needs
  - This includes re-negotiating limits and discussing priorities, workloads, and resources.
- Communicating with the rest of the organization about the team's actions and achievements
- Removing barriers to team progress
- Helping to resolve conflict
- Taking care of logistics (arranging for meeting rooms, getting supplies, etc.)

Team member

As discussed in Chapter 1 (p. 8), each team member shares the responsibility for the success of the team. As a responsible team member, you should…

- Focus on the purpose of the team
- Think less about personal goals and more about the success of the team as a whole
- Work to develop an atmosphere of trust and respect on the team
  - Treat your teammates with respect.
  - Value different ideas.
- Listen more than you talk
- Communicate clearly
- Participate fully
- Make realistic commitments and then keep them

➤ **TIP** *A team leader is also a team member and should share in the team member responsibilities.*

Team facilitator or coach

Some organizations assign experts in group dynamics, problem solving, or running meetings to help teams. This role goes by many names, such as "facilitator," "coach," and "advisor." Generally, these people focus more on how the team gets its work done than on the content or subject of the team's work.

The work these facilitators do can include…

- Providing training as needed
- Helping the team deal with conflict
- Coaching the team leader or team members on team skills
- Helping the group use basic problem-solving principles and tools
- Leading team meetings, especially when difficult or controversial subjects are being discussed. (See also p. 79)

Agreeing on Ground Rules

Why it's important to your team

Ground rules are guidelines for how the team will function. Having ground rules can…

- Improve the team's effectiveness and efficiency.
- Minimize confusion, disruptions, and conflicts that take away from the real work.

Why it's important to you

- A clear understanding of your team's ground rules can help you know what is expected of you and avoid conflict with others.
- By helping your team set up its ground rules, you can make sure your concerns about how the team operates are taken into consideration.

➤ **TIP** *Each team should discuss and agree to its own guidelines.*

What you can do

- **Find out what your team's ground rules are**
  - If your team has not already defined its ground rules, suggest the issue be discussed in a team meeting.
- **Understand what the ground rules mean**
- **Use the ground rules to shape your own behavior**
  - Participate fully in discussions when the ground rules are being set up. Make sure your ideas and concerns are raised.
  - Stick to the ground rules yourself.
  - Remind the team of particular ground rules when appropriate.
    "Remember that this discussion should be kept confidential."

When rules are broken

All teams violate their own ground rules on occasion. If a ground rule is broken repeatedly, however, you (and your team) need to decide whether or not it's a problem. If it is, consider giving feedback to the rule breaker or discussing the issue as a team. If not, change the ground rule.

Examples of ground rules

This page and the next give examples of typical ground rules.

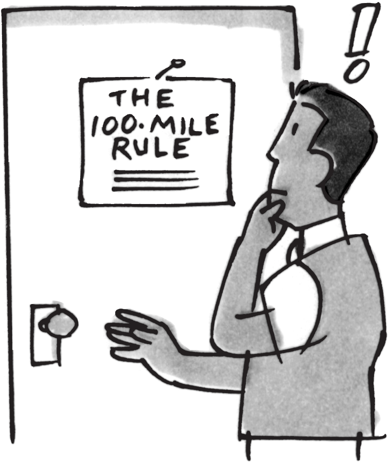
- **Decision making**
  We will make important decisions by consensus.
- **Use of data**
  As much as possible, we will base our decisions on data.
- **Confidentiality**
  Information shared in team meetings can be shared with others in the organization unless a team member asks that it be kept confidential.
- **Assignments**
  All assignments should be done on time. If you can't get them done, notify the team leader as soon as possible.
- **Participation**
  Everyone will get a chance to voice their opinions.

➤ **TIP** *Be flexible and realistic. Think of ground rules as general guidelines, not rigid laws.*

Examples of ground rules, cont.

- **Meeting ground rules**
  Attendance: We will only meet when a majority of members can be there.
  Starting on time: We will start promptly at 8:30 A.M. Everyone is expected to be here and ready to go at that time, with all the materials and information they need.
  Rotation of roles and responsibilities: We will rotate who will take notes.
- **Meeting evaluation**
  The last 5 minutes of each meeting will be spent discussing how we can improve next time.

➤ **TIP** *Post the ground rules in your team's meeting room.*



The 100-Mile Rule

Once a meeting begins, everyone is expected to give it their full attention. However, it's often hard for people to separate themselves from other work going on. To help coworkers know whether to interrupt the meeting, some teams invoke the "100-mile rule": No one should interrupt the meeting unless it's so important that the disruption would occur even if the meeting was 100 miles away. Be sure you communicate this clearly to your coworkers.

Arranging Logistics

Why it's important to your team

The time available to do a team's work is always limited. Arranging the logistics—such as making sure people know when and where to meet and having the right equipment and supplies available—helps you operate more efficiently.

Why it's important to you

Have you ever wandered around your building wondering just where your team is meeting, or wasted time waiting for someone to track down the right supplies? If so, you know how helpful it is to have the team logistics clearly spelled out.

What you can do

- **Find out where and when your team is meeting**
  - Ask that meeting times and places be discussed at the first team meeting.
  - Make sure you leave enough time to get to the meeting space or work area on time and fully prepared.
- **Help identify and get adequate supplies**

Examples of logistics

The following list includes several of the most common logistical questions that teams need to address.

- How often will the team meet?
- Where will the team meet?
  - Will the meeting place change?
- What time will meetings start?
- How long will meetings last?
  - Will they always be the same length or will it change from week to week?
- How will the team accommodate people who work at different sites or on different schedules?
- Where can the team get equipment and supplies for the meeting?

CHAPTER 2: ACTION TIPS

Here are some ideas about taking action on the start-up topics described in Chapter 2.

- *As a team member, you cannot act alone on any of these issues. The key is to look for ways you can help your team make these preliminary decisions about how it will operate.*

- *Make sure you know the purpose of any team you're on. Ask your team leader if there is a written purpose statement.*

- *Keep track of the stakeholders—customers, managers, coworkers, suppliers—that you are likely to run into on the job. Keep them informed of your team's progress. Try to identify and address potential sources of resistance to the team's activities.*

- *Check to see if each team that you're on has created ground rules for its meetings. If they have, make sure you follow them. If you find any of the ground rules unreasonable, ask that they be discussed at a team meeting.*

CHAPTER 3

GETTING WORK DONE IN TEAMS

Quick Finder

Team Work Methods Checklist

Here is a checklist of basic methods for getting work done in teams.

How often does your team…	Rarely	Sometimes	Often
Create **work plans** (p. 64)	○	○	○
Have productive **meetings** (p. 71)	○	○	○
Use **data** (p. 87)	○	○	○
Make good **decisions** (p. 92)	○	○	○
Evaluate potential **solutions** (p. 96)	○	○	○
Implement **changes** (p. 100)	○	○	○
Check progress (p. 103)	○	○	○
Document its work (p. 108)	○	○	○

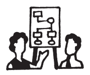
Working in Teams

Working as part of a team is different from working on your own. It requires techniques that help teams maintain focus and develop a common understanding of issues. For example…

- Planning helps team members know what is expected of them individually and collectively.
- Effective meetings allow team members to share and exchange ideas and contribute to the team's progress.
- Evaluating alternative solutions helps the team draw on all team members' knowledge and experience, and make better choices.

Tips on using this chapter

The topics in this chapter are arranged roughly in a sequence that matches a team's progress. Planning and having meetings, for instance, come before making decisions and implementing changes. Use the checklist on the facing page to help you find topics that match where your team is.



Creating Work Plans

Why it's important to your team

It's possible to get work done without a plan. We all take actions every day that are not planned. But there are many advantages of planning. A plan…

- Helps a team coordinate the efforts of all the team members—it provides clear direction for team members on what they should be doing and when.
- Identifies targets and deadlines the team should commit to meeting.
- Makes sure key steps in a task or activity are not missed.
- Provides the basis for checking progress.
- Helps you identify potential conflicts in schedules.
- Helps you identify needed resources.

➤ **TIP** *A plan documents what your team wants to have happen. Periodically compare this to what actually happens. Modify your plans accordingly and think about how to create a more realistic plan the next time around.*

What you can do

- **Help your team develop a useful plan**
  - Suggest steps needed to accomplish a given task.
  - Use your knowledge of how work gets done in your organization to help the team estimate how much time and what resources will be needed.
  - Help identify potential barriers that might stand in the way.
- **Use your team's plan to guide your actions**
  - Be clear about your role in making the plan work.
  - Use the plan to identify what work you should be doing and when.
  - Be responsible for completing the tasks that you have volunteered for or that were assigned to you.

➤ **TIP** *If you find yourself doing work that is not part of the plan, check it with your team. Make sure it will contribute to the team's progress.*

Building your planning skills

Knowing how to create a plan is a valuable skill that will help you in all aspects of your work, not just on the team. If you have not done much planning before, here is a list of key steps involved in creating a plan.

- ***Identify what you want to accomplish.***
- ***Identify the main activities** or steps needed.*
- ***Estimate** about how much **time** and what other **resources** are needed.*
  - *How much time will each step take?*
  - *Which people are involved with each step?*
  - *What equipment, supplies, or money will you need?*
- ***Identify measures of progress**: How will you know if the plan is working? How will you know if you are getting the results you need? (See p. 103)*
- ***Create a document** that shows the basic elements of the plan. (See the examples on pp. 69 and 70)*

Examples of planning tools

There are many tools that help you capture the basic elements of a plan (listed on p. 68). Two common tools are **planning grids** (p. 69) and **deployment flowcharts** (p. 70).

- A planning grid is often the simplest tool to use. You only need to list the steps or actions down the side of a page and add other important information—such as who is involved and how much time is needed—in other columns.
- A deployment flowchart is particularly useful when the work involves many handoffs between different groups or people.

Basic elements of a plan

The numbers correspond to the plan shown on the next page.

❶**Steps or tasks**
List the actions, in sequence.

❷**Desired outcome**
Indicate what each step will accomplish.

❸**Who is responsible**
Enter the name of the person or group in charge of each step.

❹**Planned start and end dates**
When should each step start? When should it end?

❺**Actual dates**
Leave room on the plan to document when the steps actually start and end.

❻**Comments**
Leave room for capturing notes about what really happens and lessons learned.

❼**Other columns** can be added

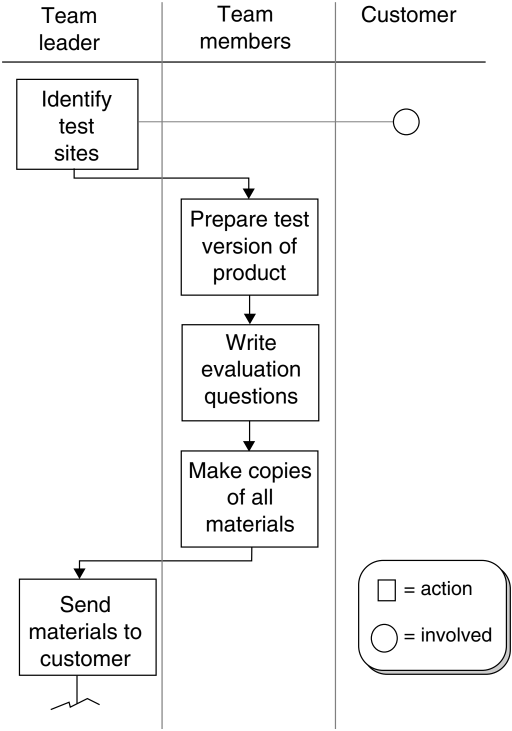
- Budget and expense notes
- Other key people to involve in key steps
- Notes on limits or boundaries
- Hazards or pitfalls

Example of a planning grid

This planning grid shows the first steps a team used to identify and make service improvements.

Step #	❶ & ❷ Step and Desired Outcome	❸ Who	Dates		❼ time/$$ limits	❻ Comments
			❹ Plan	❺ Actual		
1	Search files to identify existing customer data	Otis Marc	**Start:** 3/15 **End:** 3/22	3/15 3/27	1 wk/ no $	Computer breakdown on 3/17
2	Contact key customers to understand current needs	Shelly Trisha	**Start:** 3/23 **End:** 4/6	3/28 4/7	2 wks/ $500	Good support from marketing made up some lost time
3	Hold meeting to select service improvement targets	Whole team	**Start:** 4/10 **End:** 4/10	4/10 4/10		Meeting went well; good prep

Example of a deployment flowchart



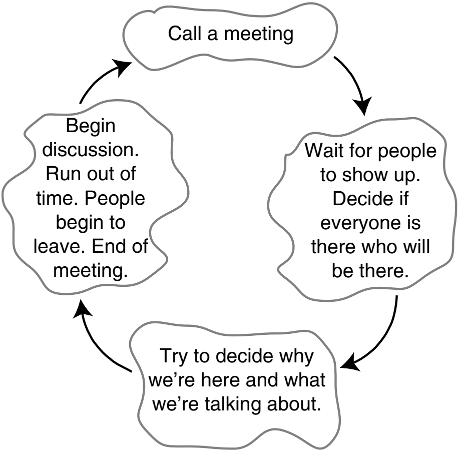
This deployment flowchart captures the basic steps of a plan for conducting a test. It shows the sequence of steps and who is responsible.

Having Productive Meetings

Why it's important to your team

Meetings are often treated as things that "just happen." Poor meetings sap a team's energy and can lead to a slow and painful death. Meetings where the team accomplishes its goals will keep momentum going and contribute to rapid progress.

Wrong Way to Hold Meetings



What you can do

- **Help your team have productive meetings**
  - Use the meeting process (shown on pp. 74 and 75) to help your team create a plan for each meeting.
  - Contribute to discussions.
  - Offer to take notes, keep track of time, or lead a meeting.
  - Contribute ideas for improving your meetings.

- **Work on your own meeting skills**
  - Review the agenda before the meeting and come prepared.
  - Improve your own discussion and listening skills. (See Chp. 1, pp. 12 and 15)

✓ Checklist of meeting methods

The following pages cover some of the most useful tools and methods used to run effective meetings. Which of them do you and your team use?

	Yes	No
We follow a **meeting process** (p. 74)	○	○
We use **agendas** to keep the meeting organized (p. 76)	○	○
We assign **meeting roles**		
Meeting leader (p. 79)	○	○
Notetaker (p. 81)	○	○
Timekeeper (p. 83)	○	○
We **evaluate** our meetings (p. 85)	○	○

➤ **TIP** *The communication skills described in Chapter 1 are also helpful in having good meetings. See the sections on listening (p. 15), discussion skills (p. 12), and feedback (pp. 21 to 25).*

Example meeting process

This two-page flowchart shows a general sequence of events in a meeting. Use it to help you plan your own participation in your team meetings.

BEFORE

1. Plan

- Clarify meeting purpose and outcomes
- Identify meeting participants
- Select methods to meet purpose
- Develop and distribute agendas
- Set up room

DURING

2. Start

- Check-in
- Review agenda
- Set or review ground rules
- Clarify roles

3. Conduct

- Cover one item at a time
- Manage discussions
- Maintain focus and pace

Example meeting process, cont.

DURING

4. Close

Summarize decisions

Review action items

Solicit agenda items for next meeting

Review time and place for next meeting

Evaluate the meeting

Thank participants

AFTER

5. Follow Up

Distribute or post meeting notes promptly

File agendas, notes, and other documents

Do assignments

Meeting agenda checklist

Meeting agendas help people know what to expect in a meeting. If you are involved in creating agendas for your team, here is a checklist of typical information to include.

❍ Items to be discussed

❍ Person or people leading the discussion for each item

❍ Desired outcome for each item, such as

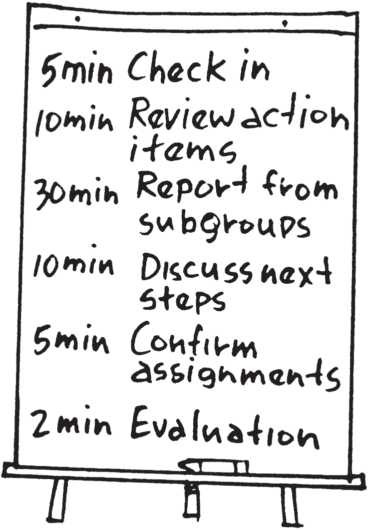
  – List of ideas or options
  – Shared understanding
  – Priorities
  – Decision or recommendation
  – Action steps

❍ Estimated time for each item

❍ Meeting evaluation

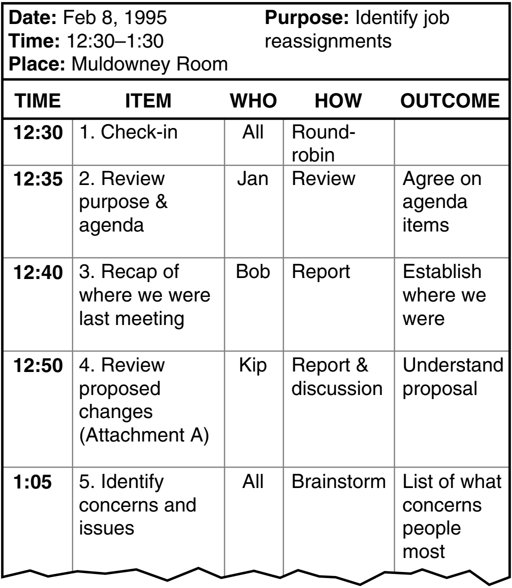
➤ **TIP** *You may not need to include all this information if you have regular meetings with standard agenda items (see p. 77). But be sure to include more detail when you are discussing complex or "hot button" issues (see p. 78).*

Example: A simple meeting agenda



This simple agenda was written on a flipchart at the beginning of a regular team meeting. It has only the items for the meeting with allotted times. It was not sent out ahead of time, and everyone who attends this meeting knows what is meant by these topics so no further detail was needed.

Example: A detailed agenda



Date: Feb 8, 1995
Time: 12:30–1:30
Place: Muldowney Room

Purpose: Identify job reassignments

TIME	ITEM	WHO	HOW	OUTCOME
12:30	1. Check-in	All	Round-robin	
12:35	2. Review purpose & agenda	Jan	Review	Agree on agenda items
12:40	3. Recap of where we were last meeting	Bob	Report	Establish where we were
12:50	4. Review proposed changes (Attachment A)	Kip	Report & discussion	Understand proposal
1:05	5. Identify concerns and issues	All	Brainstorm	List of what concerns people most

Here is an agenda used at a meeting to discuss job reassignments. The agenda was prepared and sent out ahead of time to all participants. That helped people know what information to bring to the meeting and to come prepared to discuss the issues and share their concerns.

Example: The meeting leader role

Having someone lead a meeting can help keep it on track and running smoothly. The meeting leader…

- Opens the meeting
- Reviews the agenda with the group; makes changes as appropriate
- Makes sure there is someone to take notes and someone to keep track of time
- Moves through the agenda one item at a time
- Facilitates discussions
- Helps the team choose appropriate discussion and decision methods
- Has the group evaluate the meeting
- Gathers ideas for the next meeting
- Closes the meeting

Leading vs. Facilitating

This description of a meeting leader includes "facilitation"—the work that goes into making meetings run smoothly. In practice, other team members often help facilitate the meetings.Teams that are inexperienced or that are having difficult times may benefit from having an outside facilitator or coach brought in to facilitate meetings. (See also p. 52)

Building your meeting leader skills

If you get the opportunity to lead a meeting, here are a few tips to help you out:

- ***Take your time.*** *Your teammates will understand if you need a little extra time to organize your thoughts.*
- ***Use the agenda as your guide!*** *A well-organized agenda is a meeting leader's best friend.*
- ***Ask someone to write key points and action items*** *on a chalkboard or flipchart in full view of the whole team.*
- ***Don't be shy about asking for help*** *from the other meeting participants.*

"I'm not sure how to get us back on track here. Can anyone offer some suggestions?"

"Can someone summarize the main points of the discussion so we can capture them in the notes?"

➤ **TIP** *Knowing how to lead meetings is a valuable skill that will benefit all team members. Ask that your team rotate this responsibility.*

Example: The notetaker role

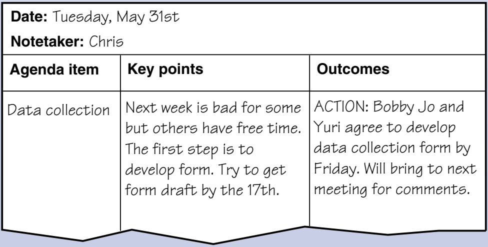
Few people like to take notes at a meeting. Often the problem is that they think the task is more difficult than it needs to be. A notetaker's responsibilities include…

- Capturing the key points for each agenda item.
  - It's seldom necessary to capture everything that is said word for word.
- Highlighting decisions, action items, and issues that will be deferred until future meetings.
- Copying minutes and seeing that they are distributed or posted.
- Filing one copy of the meeting notes in the team's official records.
  - Include copies of any handouts, charts, etc. that were used at the meeting.

Building your notetaking skills

The tips below can help make the job of taking notes much simpler.

- ***Speak up** if you don't understand what is being said or what decision is being made.* "I'm not sure what to put in the notes about this. Is Charlotte agreeing to contact Jerry about getting new equipment?"
- ***Use a standard form** that provides space for the key items your team wants to capture.*



Date: Tuesday, May 31st

Notetaker: Chris

Agenda item	Key points	Outcomes
Data collection	Next week is bad for some but others have free time. The first step is to develop form. Try to get form draft by the 17th.	ACTION: Bobby Jo and Yuri agree to develop data collection form by Friday. Will bring to next meeting for comments.

- ***Check if handwritten notes are OK.** You can often just photocopy the notes for distribution.*
- *If you are more comfortable working at a computer keyboard than writing notes, **see if your company has a portable computer available.***

Example: The timekeeper role

A team's time together is precious. Yet often when the end of a meeting rolls around the team finds it has not gotten to half of the agenda items. To use meeting time wisely…

- Include times for each agenda item.
- Designate a person to act as a timekeeper.
- Periodically check how close the estimates were to how much time was actually spent on each item.

➤ **TIP** *Allow flexibility in the schedule. Let the group decide when it's OK to let an agenda item run longer than originally planned and when to cut a discussion short. Do NOT simply police the agenda ("Time's up. Move on.").*

➤ **TIP** *Help your team be realistic about how much to include in an agenda so you don't always get crunched for time.*

Building your timekeeping skills

If the responsibility of keeping time falls to you, here are some guidelines you can use.

- ***Check** how much time is allotted for an item.*
- ***Alert** the group when time on any given item is running out.*

  "There are two minutes left. Can we wrap up or should we allow more time?"

- ***Signal** when time is up.*

Example: Evaluating and improving meetings

Taking time to evaluate meetings is the hallmark of a team that wants to make rapid progress. There are several ways to do an evaluation:

- Round-robin comments—go around the room and let everyone share their ideas in turn
- Written evaluations shared with the group
- Open discussion (anyone speaks in any order)

Evaluation questions

- ***General questions*** *about the meeting*
  - *What can we do better next time?*
  - *What parts of the meeting worked well?*
- ***Specific questions*** *about issues your team wants to improve*
  - *Did we stay on time? Did anyone feel rushed? Did the meeting seem to drag?*
  - *Did everyone contribute?*
  - *Were people open-minded?*

Example: Written evaluation form

Our meeting today was:

Focused	1	2	3	4	Rambling
Productive	1	2	3	4	A waste

The pace was:

Too fast Just right Too slow

Everyone got a chance to participate:

Yes Somewhat No

Our purpose was:

Clear 1 2 3 4 Confused

We made good progress on our plan:

Yes Somewhat No

At our next meeting we should:

Do more of:

Do less of:

Using Data

Why it's important to your team

Using data effectively can help your team…

- Identify issues to work on and develop focus.
- Make better decisions.
- Understand the nature and extent of problems.
- Resolve conflicts and differences of opinion.
  "Let's get some data on what our customers say is important."

What you can do

- **Support the use of data on your team**
  - Be open to checking your beliefs and opinions with data.
  - Ask other people if they have data to support their beliefs and opinions.
  - Help identify places where data would be helpful.
- **Improve your own skills in collecting, analyzing, and interpreting data**

Example: Uses of data

The following pages show four uses of data:

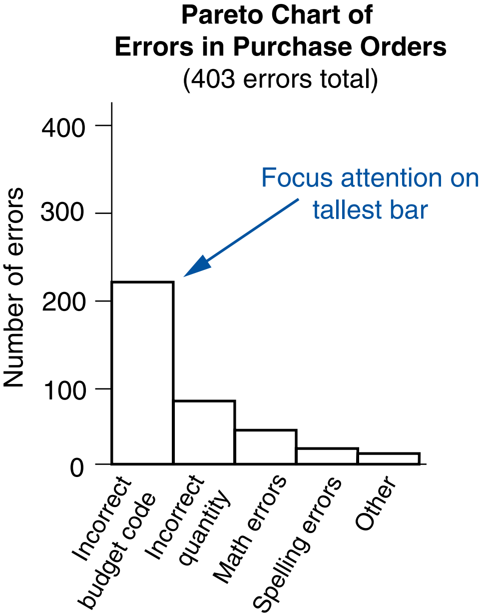
- To develop focus (p. 89)
- To pinpoint problems with a process or product (p. 90)
- To investigate possible causes of problems (p. 91)
- To see the effect of changes (included under "Checking progress," p. 106)

Building your data skills

Being able to collect and use data is another skill that you will find useful in all aspects of your work.

- *Take advantage of any training your company offers on using data tools.*
- *The more experience you can get, the better. Volunteer to help your team collect data.*
- *If you have not collected data before, ask for help from more experienced people.*
- *Practice collecting data on something in your personal life. For example, collect data on your car's gas mileage or your household expenses.*

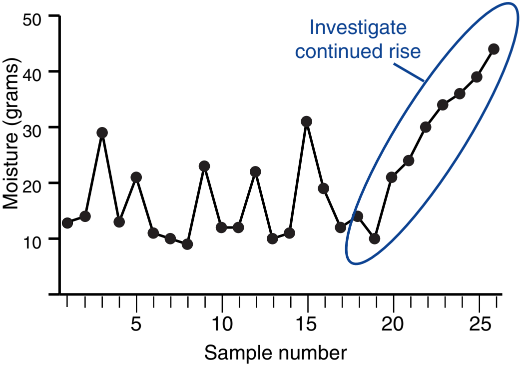
Example: Using data to develop focus



The **Pareto chart** above helped a team identify where to focus its improvement efforts. The biggest contributor to problems was errors in budgeting codes.

Example: Using data to pinpoint problems with a product or process

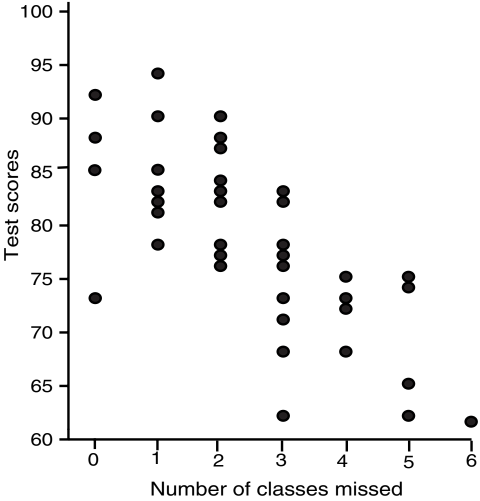
Time plot of moisture content



A team that was interested in the amount of moisture in a certain product charted data on a **time plot** (shown above). The appearance of a pattern like the one circled indicates the team should look for something special happening in the process. A time plot is also called a **run chart**.

Example: Using data to investigate possible causes

Scatter plot of test scores vs. number of classes missed



The **scatter plot** above was created by a teacher who wanted to see if attendance in classes really did affect test scores. Though there is some scatter to the points, students who attended more often generally did better than those who did not.

Making Good Decisions

Why it's important to your team

Good decisions don't just happen. Pay attention to how different decisions get made.

What you can do

- **Help to clarify what decision is being made**
  - Ask questions.
    "Is this decision about all overtime policies or just for this one occasion?"
- **Help outline pros and cons of the choices**
- **Help choose a decision method**
  - Different decisions require different levels of support and commitment. (See pp. 94 and 95)

- **Check for agreement**
  - Don’t assume that people agree just because they don’t speak up. Watch their body language.
  - Formally check with the group periodically.
    “This seems to be our agreement. Is there anyone who is unsure about the choice or other things we haven’t considered yet?”

A good decision…

- *Is supported by the people affected by it.*
- *Is based on facts and data, not just opinion.*
- *Is checked against experience.*
- *Is made knowing what the consequences will be (and these have been dealt with ahead of time as much as possible).*
- *Is made quickly enough to meet deadlines but not so quickly that important information and people are ignored.*

➤ **TIP** *To make better decisions, work on your listening and data collection skills.*

Examples of decision methods

This page and the next describe the two most common ways to make decisions: consensus and voting.

Consensus

Consensus means finding an option that all team members will support.

- Consensus does NOT mean that everyone is totally happy with the decision.
- To reach consensus you need to consider the ideas, feelings, and situations of all team members, not just of a few or even just of the majority.
- Reaching consensus usually takes a lot of discussion time and requires skills in resolving differences of opinion.
- The investment in time is usually worth it, however. Consensus decisions can often be implemented smoothly since they are supported by the entire team.
- Use consensus for complex or important decisions that require the coordination and understanding of all team members.

Voting

Each team member gets one vote. The choice with the most votes wins.

- Voting is easy and familiar.
- It is OK to take a vote for relatively unimportant decisions, but remember it can leave the "losers" feeling left out.
- While taking a vote is a faster way to make the decision, pushing for consensus often makes implementation much faster!

➤ **TIP** *Explore important issues by polling. Go around once and have each member just state how they vote. Then do a round where people briefly give one or two reasons for their vote.*

Delegating decisions

In some cases, the team may let one or a few team members make a particular decision. This works well when the decision requires particular expertise or when time is short.

> "Chris and Zola will be responsible for getting input from the whole team, but then they can make the final call on which vendors to use."

Evaluating Potential Solutions

Why it's important to your team

Many teams rush to implement the first solution that comes to mind. However, it's usually better in the long run to evaluate a number of possible solutions before making any changes. This helps a team choose the best option and be creative in combining the best aspects of several options.

What you can do

- **Help your team identify and evaluate potential solutions**
    - Generate a list of criteria before you discuss the options so you'll know how to interpret your discussions.
      "Do we go with Option A because it's cheaper? Or is it better to go with Option D because it's quicker?"
    - Brainstorm possible solutions. Be creative.
    - Evaluate solutions against the criteria.

- **Be as objective as possible**
  - Gather information on the strengths and weaknesses of all proposed solutions, including your favorite.
  - Be open to new perspectives.
  - Think creatively about how to address concerns others have with your favorite solution.
  - Be willing to combine parts of different solutions.

Examples of ways to evaluate potential solutions

The following pages show examples of several techniques for evaluating the pros and cons of different solutions.

- The **solution checklist** (p. 98) provides an overview of information you may find helpful
- The **solution matrix** (p. 99) is a quick way to capture key points for each potential solution

➤ **TIP** *Allow people time to think carefully about pros and cons of different alternatives and to check ideas with others not on the team. Often this means continuing the discussion over several meetings.*

Solution checklist

Here is a checklist of common criteria used to evaluate proposed changes or solutions.

○ **Cost**

- Dollars, time, additional investments needed (new equipment, for example)

○ **Impact** on the organization

- Which employees will be affected and how
- Training needed

○ **Potential benefits**

- Improvements customers will see
- Savings in time, money, or hassles
- How the change will help position the company better for the future

○ **Potential problems**

- Anticipated problems and potential prevention or remedies

○ **Ease of implementation**

➤ **TIP** *This information can be summarized in a **solution matrix**, like the one shown on p. 99.*

➤ **TIP** *Use data as often as possible.*

Example of solution matrix

The solution matrix below shows options a company considered when deciding whether to replace a receptionist who was leaving or find a new way to handle incoming calls.

Solution	Cost	Benefits	How Hard or Easy	Potential Problems
Send all incoming calls directly to customer service area	2 hrs technician time to reprogram & test phones 30 minutes training for C.S. staff $0	Does not require additional staff Uses current technology Get a person answering the phone	Easy Can implement immediately	Callers could wait in queue several minutes while C.S. reps. are taking orders or answering questions
Hire a new receptionist	Salary and benefits $200 advertising	Continue providing fast responses to incoming calls Get a person	Moderately easy Will take 6 weeks to	Filling receptionist position means staffing needs in C.S. won't be met

Implementing Changes

Why it's important to your team

Coming up with ideas about what needs to be changed is often the easiest part of a team's work. Making the changes takes planning, follow-through, and cooperation. Doing it well will increase the odds that your team will see its ideas put to good use. Not doing it well may mean all your hard work will go to waste.

Two keys to making changes well are **planning** and **communication.**

- Good plans help your team manage its resources and time.
- Good communication helps changes go more smoothly and makes sure nothing important is missed.

The power to make changes

Some teams have the power to make changes in the workplace, usually within certain limits or boundaries (see p. 44). Others are asked just to come up with recommendations. Before making changes, be clear about your team's limits and authority.

What you can do

- **Help draft a plan for making the changes**
- **Help implement the changes**
  - Identify what role you can play in making the changes happen. Follow through on your commitments.
  - Volunteer for tasks such as updating training or work documents.
  - Discuss proposed changes informally with coworkers. Explain how and why the changes are being made and how it will affect them. Listen to their concerns.
  - Pay attention to what happens when the changes are made. Look for things that are working well or aren't working well, and for both intended and unintended effects.
- **Give the changes a chance to work**

Example of ways to make changes

The next page describes one method that can be used to make changes.

Example of a method for making changes

- Develop a **plan.** (See p. 64)
  - Be sure to identify ways you will know if the change is working.
- Try the change on a **small scale**.
  - Look for ways to test the change with only a few people or in a small part of the work area.
  - Carry out the change and check to see if it worked.
  - Identify ways to improve the change.
- Implement the changes **full-scale**.
  - Document how the new or updated procedures should work.
  - Train everyone in the new procedures.
- Periodically **check** on how well things are working. (See p. 103)

➤ **TIP** *Much of the time, you will get some resistance to the changes your team wants to make. Involving other people in planning and implementing these changes can greatly reduce resistance.*

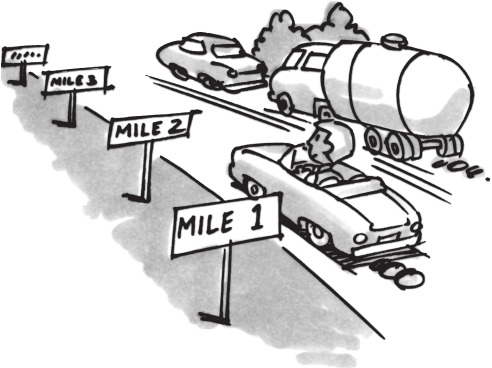
Checking Results and Progress

Why it's important to your team

Many teams fall into a trap of making changes and assuming they will get the results they wanted. Effective teams, however, know that it's critical to monitor results, check progress, and modify the changes as needed.

What you can do

- ***Before* the change, help your team understand the current situation**
  - What happens now in the workplace? Volunteer to help collect data or other information.
- **Help to identify "measures of progress"**
  - What will be different if the change has the desired effect? (See p. 105)
- ***After* the changes, help your team collect new data**
  - Prepare "before" and "after" charts displaying the results. (See p. 106)



Examples of ways to check progress

The next few pages describe some helpful techniques for checking progress.

- First, identify **measures of progress**. (See p. 105)
- Create **simple displays** of "before" and "after" data. (See p. 106)
- Track results by adding an extra column to your planning grid (discussed earlier in the chapter, p. 68), or create a new **check form**. (See p. 107)

Examples of measures

The key to identifying measures of progress is to think about how you will know if your purpose is being achieved. For instance, what will be…

– different?	– improved?
– increased?	– reduced?
– eliminated?	

Here are a few specific examples of what you could measure:

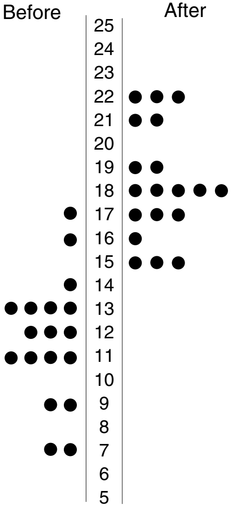
- Number of hours to produce a specific document
- Number of days in the hospital after surgery
- Reasons for phone calls to the customer support line
- Number of defects per thousand pieces a machine produces
- Percent reduction in time to complete a process
- Percent increase in equipment uptime

➤ **TIP** *Review your team's purpose statement. It should give you clues on what to measure.*

Example of using data to check progress

The chart below shows how many foul shots a basketball player made out of each 30 tries before and after training. The data values from after the training are clearly much higher than before the training.

Number of baskets made out of each 30 tries, before and after



Example of a form used to check progress

Step	Completion Dates		Hours	Comments
	Plan	Actual		
#1. Develop training materials	2/3	2/12	28	Discovered we didn't agree on steps
#2. Test with 3 people	2/22	3/1	8	They wanted more diagrams
#3. Improve materials	3/8	3/8	4	

This simple form was used by a team to track the progress of its plan and to document follow-through of key issues.

This basic form can easily be adapted to let a team capture more details on information such as amount of improvement made, cost savings, and so on.

Keeping Records and Documentation

Why it's important to your team

During a team's lifetime—be it weeks, months, or years—members will discuss countless issues, look at a lot of data, take many actions, and so on. Accurate records of what your team does and accomplishes helps maintain forward momentum and prevent rework.

What you can do

- **Help your team keep accurate and complete records**
  - Volunteer to take notes at meetings or organize the results of data collection efforts.
  - Make sure information you help to gather is captured in your team's records.

Examples of team records

The list below shows four of the most common types of team records, but you may have others.

- Notes from meetings
- Data records, including graphs and charts
- Results of customer surveys
- Reports summarizing the team's progress and achievements

CHAPTER 3: ACTION TIPS

- *Remember that you share responsibility for the team's success. Contribute to discussions, help develop plans, offer opinions when the team is making decisions, and so on.*

- *Take every chance that comes to you to develop your personal skills in these areas. The more of these skills you have, the more valuable you will be to your organization.*

- *Encourage your team to experiment with different kinds of decision making. See what works best in different situations.*

- *Develop simple data-based measures to track your own work. For example, take data on how long it actually takes to complete tasks compared to what you thought it would take.*

CHAPTER 4

KNOWING WHEN AND HOW TO END

Quick Finder

Closure Checklist

The following checklist covers the main signals that tell a team its current effort should be brought to a close. How many of them apply to your team?

	Yes	No
We **accomplished our purpose** (p. 114)	○	○
We took steps to **maintain the gains** (p. 116)	○	○
We **completed the documentation** of our actions, results, and ideas for future improvements (p. 120)	○	○
We **evaluated** our work (how we worked together and what we accomplished) (p. 124)	○	○
We **shared results** with others (p. 126)	○	○
We **recognized** everyone's contributions and **celebrated** our achievements (p. 132)	○	○

When It's Time to End

Sooner or later, every team has to end something. Project teams, for instance, may be finishing their work while ongoing teams may just be completing a particular effort. The question is how you want to end. Letting achievements go unrecognized can be disheartening. To end on a positive note…

- **Evaluate and documen**t the team's work, achievements, and lessons learned.
- **Maintain the gains:** Take steps to make sure the changes and improvements made by the team will continue.
- **Share results** with your organization.
- **Recognize and celebrate** the contributions that made the team's achievements possible.

Tips on using this chapter

The methods described in this chapter cover the main themes mentioned above. Use the checklist on the facing page to help you decide which of the items your team has completed and which need further attention.

Knowing You Have Achieved Your Purpose

Why it's important to your team

If your team does not know how to tell when its purpose is accomplished, it could end up stopping too early or too late.

- If a team's work ends before sufficient progress has been made, your organization may suffer business losses.
  - This often includes increased costs, quality that is less than it could or should be, failure to meet customer needs, rework down the road, and so on.
- If it continues for too long, the organization pays in other ways.
  - For example, the team may have missed out on other improvement opportunities by focusing too long in one area.

Being able to judge when you have accomplished your purpose helps your team and your organization use its resources wisely.

What you can do

- **Help your team identify appropriate indicators or signals**
  - The time to figure out how you will know when you are done is at the beginning of a project or effort. (See Chp. 2, p. 44)
  - Think about what will be different when you are done. What will be better? What will be happening or not happening? What will the data look like? (See Chp. 3, p. 104)
- **Help your team recognize when its purpose has been accomplished**
  - Regularly review the data and other information your team is gathering.
  - Compare this information to indicators you have identified.
  - Let your team know when you think it has made sufficient progress.

Maintaining the Gains

Why it's important to your team

Many teams have been disappointed when they realize that improvements they made have been lost. Teams need to do whatever they can to make sure the changes they have made are preserved.

What you can do

- **Help your team identify changes that will make it easy for people to use new procedures and hard for them to backslide to the old methods**
  - Help document exactly what is being changed. Who has to do what and when?
  - Think about how the procedures can be made error-proof. What could prevent people from using old methods? What will make it easy to use the new methods?

- **Help to update appropriate documentation**
  - Identify any job aids used to do the work. This includes manuals, diagrams, flowcharts, computer records, or other work instructions.
  - If you have the authority, update these job aids as needed. If not, come up with recommendations for your manager or supervisor.
- **Help to develop a plan for getting the new methods well established**
  - Include a plan for trying out updated training, procedures, and documents on a small scale.

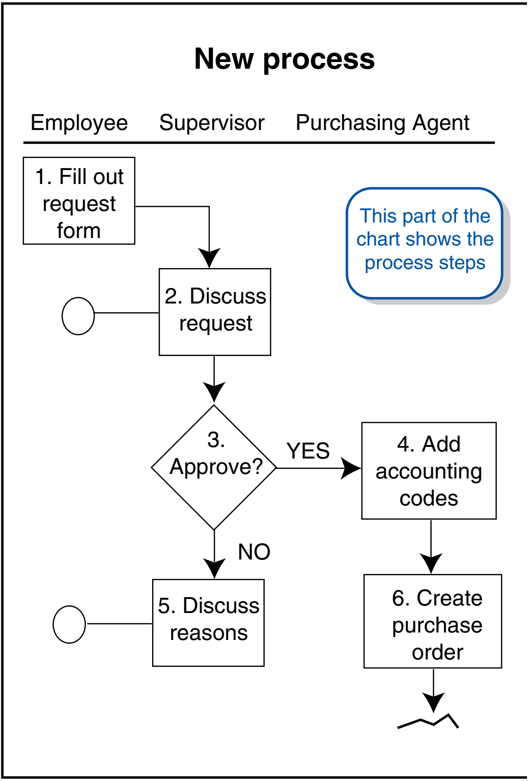
Example of updated job aids

The following pages show a job aid that helped people use a new procedure.

- A **deployment flowchart** can show people how different tasks relate. This sample also includes space for brief notes on what should be measured on this process and what actions to take as a result.

Example of form for maintaining gains

The form on these pages was used to help



New process

This part of the chart shows the process steps people manage a purchasing process.

This part of the chart shows how to monitor the process and what actions to take

Measures (Who tracks what)	**Actions** (What to do about it)
3. Supervisors track # of requests approved and denied.	3. Create chart showing monthly figures. Alert manager if rises abruptly or over time. Look for patterns over time.
4. Purchase agent counts # of requests where it is not clear what code to use.	4. Alert supervisor if not clear what code to use. Develop new codes as needed. Revise request form.

Completing Your Documentation

Why it's important to your team

A team's documentation serves as the organization's memory of what happened on the team—what was learned, what was gained. Having every team document its efforts is a key ingredient in creating rapid learning and progress.

What you can do

- **Help your team update and complete its records**
    - Help your team keep track of achievements, successes, and lessons learned.
    - When it's time to end, help to compile and organize all the pertinent records.
    - Review the documents to make sure you understand them.

➤ **TIP** *Pretend it's a year down the road and you want to refer to something your team did. Will you understand the language, references, and plots in your team's documentation?*

Example of completed documentation

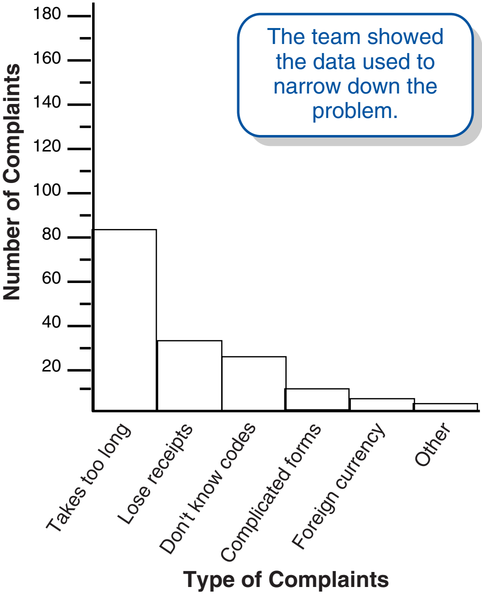
- The following two pages show excerpts from a **storyboard**. This kind of documentation relies mostly on pictures, graphs, and brief comments to capture the key points of a team's effort.

Example of a storyboard

These two pages show excerpts from the beginning
project. The complete storyboard had

Step 1: Project

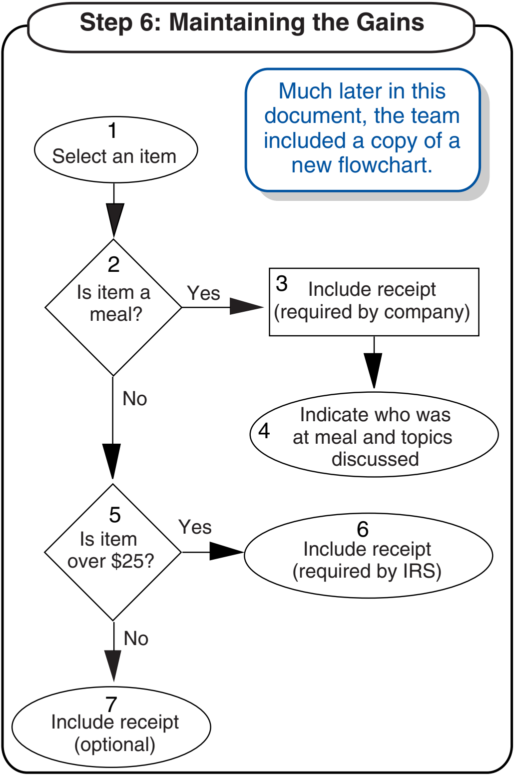
Pareto Chart of
Expense Reimbursement Complaints
Jan. 18-29, 1993



The team showed the data used to narrow down the problem.

for an administrative process

and end of a team's storyboard on its reimbursemen
information on many other steps.



Much later in this document, the team included a copy of a new flowchart.

Evaluating Your Team's Work

Why it's important to your team

Though one effort or project is coming to a close, every person on the team will probably be involved with other efforts or teams in the future. Taking time to evaluate the current effort or project…

- Helps provide a sense of closure.
- Reinforces key learnings.
- Provides the basis for ongoing improvement.

What you can do

- **Help your team evaluate its work**
  - Before the meeting when your team is going to evaluate its work, review your own documents. Jot down notes on things you liked and didn't like about the results the team achieved or how the team did its work.
  - Encourage other people on the team to do the same.

Example: Team evaluation checklist

The checklist below shows steps often taken to evaluate a team's work.

❍ **Start with a general evaluation**
  - Have everyone share their overall impressions.
  - What did the team do well?
  - What did the team have trouble with?

❍ **Review the team's achievements**
  - Did you accomplish your stated purpose?
  - If yes, what made that possible?
  - If no, what roadblocks stood in the way?

❍ **Compile a list of key learnings**
  - What did you learn about the product, service, or process that you worked on?
  - What did you learn about your customers and their needs?
  - What did you learn about working together as a team?

❍ **List ideas for how future efforts could be improved**

Sharing Results

Why it's important to your team

You and your teammates have probably learned a lot by being part of the team. It may be obvious that sharing your lessons with others not on the team can benefit them, but how can sharing results benefit you? Sharing your work…

- Helps reinforce the lessons you have learned.
- Can make the final implementation of your team's ideas go more smoothly.

What you can do

- **Help your team share its results formally with the organization**
  - Identify ways that information is shared in your organization.
  - Help your team use these outlets to publicize your accomplishments.
- **Share lessons and insights informally with your coworkers**
  - Talking with coworkers can help them feel more involved with the team.

Examples of ways to share your results

There are many ways that your team can share its results with the rest of your organization. Two of the most common, described on the following pages, are to…

- Do a presentation. This is most often done for a manager and coworkers, but is sometimes done for executives or customers. (See p. 128)
- Contribute an article to your organization's newsletter. (See p. 130)

➤ **TIP** *See if your organization has a central database, file, or record-keeping system for tracking team efforts. If so, give a copy of your team's documents to the people who maintain those records.*

Example: Preparing a presentation

- Work with your teammates to decide who will be involved in developing and delivering the presentation. **Try to involve everyone**.
- Find out who will be in your **audience.** What do they need to know? How will they use the information you give them?
- **Write notes** about what you want to cover.
  - Include a brief review of what your team did, what it learned, and what impact the work will have or has had on the organization and its customers.
  - At the end, be sure to include recommendations for next steps.
- **Make it visua**l. Many people understand charts and pictures better than words.
  - For instance, put key charts, data, or sketches on flipcharts, posters, or overheads.
- **Practice the presentation**
  - This is especially important if the whole team is involved. A practice session lets everyone coordinate their timing and key points they need to make.

➤ **TIP** *If your team's work has involved contact with customers or suppliers, try to involve them in the presentation as well.*

Example: Writing a newsletter article

Many organizations use in-house newsletters to spread information. The editor of this newsletter would probably be happy to publish the results of your team. Here is a simple outline you could use for the article.

1. Introduction

- Describe the problems or issues the team addressed and what solutions were put in place.
- Give a brief overview of actions and results.

➤ **TIP** *Open the article with a story from a customer or coworker who was experiencing the problem your team solved.*

2. Summary of major findings

- List or briefly describe the steps the team took.
- Describe the changes the team made and what the results of those changes were.

➤ **TIP** *Use data charts and diagrams to show what the team discovered.*

3. Lessons learned

- Describe what the team learned about the specific issue being studied and its impact on the organization's business needs and its customers.
- Include notes on what the team learned about how to plan, analyze problems, make changes, and so on.

➤ **TIP** *Focus on tips you think will help other people in your organization.*

4. Acknowledgments

- List all the people on your team and acknowledge the support of your departments and managers.
- Include anyone who was not on the team but who contributed to its work (by covering phones or doing extra work, for example).

➤ **TIP** *BE GENEROUS. Include anyone who supported your team's efforts.*

➤ **TIP** *Have someone take a photo of your team at work, or of the product or workplace you studied.*

Recognition and Celebration

Why it's important to your team

Everyone likes to have their contributions to an effort acknowledged. This includes not only the team members but others who helped the team. Recognizing and celebrating the team's achievements helps to reinforce the positive feelings that come from working together to solve problems.

What you can do

- **Help your team recognize everyone's contributions and celebrate everyone's efforts**
  - Keep track of people inside or outside your organization who have supported the team's efforts. Make sure these people are acknowledged by the team—invite them to the party, send them thank-you notes, post their names on a bulletin board, etc.

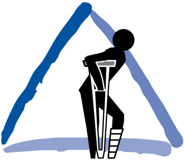
Principles of recognition and celebration

- *Recognize and celebrate* ***learning*** *and* ***contributions****, not just "successes."*
  - *Many teams do not achieve success as defined by their original purpose statement. If they document and learn from their efforts, they have gained valuable knowledge for their organizations.*
- *Keep it* ***simple****.*
  - *Examples: give an informal party with pizza or cake, bring doughnuts for breakfast, post a notice or article on a lunchroom bulletin board, give out token gifts such as t-shirts.*
- *Be* ***inclusive*** *rather than exclusive.*
  - *Include people who covered for team members, those who helped collect or analyze data, and so on.*
  - *Include people who will carry on the team's work, such as coworkers who will be implementing the changes.*
  - *Include customers, suppliers, or others outside your organization.*

CHAPTER 4: ACTION TIPS

- *Try not to get so caught up with your team that you ignore signals that tell you it's time to end—such as achieving your purpose!*
- *Recognizing and celebrating **all** contributions can make it easier for the team to disband.*
- *Recognize and celebrate significant **milestones** along the way. Celebrate early and often!*
- *Try out different ways to celebrate and recognize achievements. See which work best for your team and your organization.*

CHAPTER 5



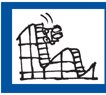
PROBLEMS WITHIN THE TEAM

Quick Finder

Checklist of Common Problems

Listed below are some common problems that occur within teams. If any of these sound like your team, look further in this chapter to see what you can do to improve the situation.

If this sounds like your team…	See …
Several people fight over everything	Conflict, p. 138
Even small arguments turn into fights	
The boss is on the team and people will not speak openly	Power, p. 144
Everyone goes along with what the expert says, no questions asked	Experts, p. 146
When the expert speaks, no one can figure out what s/he's saying	
People spend most of the meeting time telling personal stories	Focus, p. 149
People often talk about several different topics at the same time	
We have about 15 things going on and never get anywhere on any of them	
No one on our team ever disagrees	Agreement, p. 154
One team member talks all the time while others hardly say anything	Participation, p. 156
A lot of people don't finish assignments	Follow-through, p. 158



Team Problems in a Context

Most teams go through natural and expected cycles of highs and lows: excitement one moment when hard work pays off, frustration and anger the next when progress stops because of disagreements or confusion over the team's direction. The first step is to recognize that some conflict and disagreement within a team is a good sign!

- To make good choices and decisions, a team must balance the often conflicting ideas that people bring to the table.
- If there is never any disagreement on a team, it probably means people are not being honest or open about what they really think.

It's not always easy to know when a problem you see on your team is natural and normal—and something that will pass—and when it's a serious problem that needs attention.

Tips on using this chapter

Use the checklist on the facing page to identify symptoms that sound like the problem your team is having. Then review the appropriate pages in the chapter.

Handling Conflict and Disagreement

Symptoms

- **Feuding**
  - A few members fight over every topic discussed.
  - People insult and attack each other personally rather than discuss ideas.
  - People push each other into corners by exaggerating or using highly judgmental words.
- **Disagreements**
  - Emotions run high, making it hard for people to work together to resolve issues.
  - Legitimate differences of opinions tend to become win-lose struggles. People are more concerned about winning the argument than finding a path forward for the team.

Why it's important to deal with conflict and disagreement

Some amount of conflict shows that members are testing ideas and trying to come up with the best path forward. But in some cases, conflict reaches a critical stage, such as…

- When two or more team members are feuding—disagreeing and arguing over everything just for the sake of argument.
- When every disagreement is taken as a sign of unhappiness with the team or an unwillingness to get along.

In these cases, the team should actively work to reduce conflict so the team can make progress.

What you can do

- **Help your team deal with feuds that are interfering with its progress** (See p. 140)
- **Help your team find common ground when disagreements erupt** (See p. 141)
- **Be aware of your own responses to conflict and try to find ways to be less emotional when you disagree with others** (See p. 143)

Tips on dealing with feuds

- Recognize that the feud may have started long before the team existed and may outlast it. Don't try to end the feud; try to find a way to let the team move forward.
- Suggest discussion methods such as round-robins and silent "thinking" time to prevent feuding members from dominating a meeting with their arguments.
- Encourage the adversaries to discuss the issues outside of the team meetings.
- Tell the feuders about the effect they have on the team.
  "When you two go at each other, it wastes the team's time and makes it difficult for anyone else to participate without taking sides."
- Ask your team leader or manager to help members deal with their differences.

Tips on dealing with disagreements

- Listen carefully to each person's point of view.
- Help to clarify the core issue by separating areas of agreement from areas of disagreement. (See p. 142)
- Suggest discussion methods such as round-robins and silent "thinking" time when feelings start to run high.
  "Let's all take five minutes to think silently about these issues and jot down our ideas. Then we can share them with the group."
- Periodically check your understanding of the disagreement. (See also Chp. 1, p. 12)
  "As I understand it, we agree that the payroll system is the first priority, but we disagree about whether a new computer is needed. Is that right?"

Example: Outlining areas of agreement

Here is a practical way to help identify the real issues during a disagreement.

- Draw a vertical line on a large sheet of paper or chalkboard.
- On one side, write down what people agree about. On the other, write down what they disagree about.
- See if the differences between the sides are important for the team's work. If yes, help develop a plan for getting information that will help resolve the issues. If no, move on.

Tips on ways to be more objective

- Keep your comments **focused on the topic**, not on the person who disagrees with you. Say "Here's why I think that approach won't solve the problem..." instead of "Jillian, you don't understand the issues."

- **Avoid judgmental language.** Say "Here's what I'm concerned about..." instead of "That's a stupid idea."

- Make an honest effort to **understand the other person's point of view**. Ask them for more detail before giving up on their ideas. Say "I don't think I understand how your suggestion would solve the problem, Bea" instead of "I don't think that's relevant."

- If you find yourself constantly fighting with another team member, **ask for help** from your team leader, manager, or a facilitator. Do not let your feud harm the team.

- See also the section on giving feedback, p. 21.

Dealing With Power and Authority

Symptoms

- Once a manager or expert states an opinion, everyone falls in line.
- Managers or supervisors discourage discussion about their areas of expertise or authority.
- People comment that they don't say what they think "with the boss around."

Why it's important to deal with power and authority

People with more power or authority than other team members can be a valuable resource. However, they can become a barrier to progress when their power or expertise stops criticism of their opinions. This can be a problem because the soundness of all ideas should be tested before they are adopted by the team.

(If the person with more authority wants people to challenge his or her opinions, but the team members are afraid to do so, see "Too much agreement," p. 154, for ideas on what to do.)

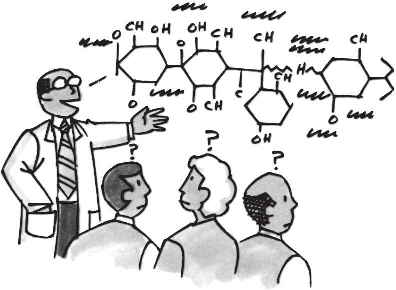
What you can do

- **Help your team avoid situations where one person's power or authority squashes contributions from other team members**
  - When setting up the team's ground rules (see Chp. 2, p. 53), suggest a ground rule that "strengths and weaknesses of all ideas will be discussed before decisions are made" or "all job titles will be parked at the door."
  - Try to make sure this ground rule is enforced consistently for all team members, not just for the person with the power or authority.
- **Speak up when you think someone's power or authority is hurting the team**
  - Ask your team leader to talk to the person outside of a team meeting. If the problem is with your team leader, speak to him or her first or ask a manager or supervisor for help.

Dealing With Overbearing Experts

Symptoms

- Experts discourage discussion about their areas of expertise.
- Experts use technical jargon or refer to complex principles without explaining things in plain English.
- Team members follow the expert's advice without any challenges or questions. They consider no other perspectives.
- If a team member questions an expert, or offers a different opinion, other team members may brush those ideas aside and try to silence the differences of opinion.



Why it's important to deal with overbearing experts

Many teams deal with complex issues in the course of their work. Having experts on the team can…

- **Help** by providing team members with a deeper understanding of the technical aspects of their work. In this way, experts can contribute significantly to the team's success.
- **Hurt** if they discourage discussion of their recommendations or seem to believe that their advice need not be explained. This can leave team members confused and frustrated, and may mean the team will miss important information that would have emerged from open discussions.

For team members to support the team's work, they must have the chance to discuss all issues.

➤ **TIP** *Remember, too, that a non-expert can often provide a fresh viewpoint that will give a team new insight on a problem or situation.*

What you can do

- **Help your team use its experts wisely**
  - Do not let your team substitute "expertise" for "discussion." The expert's ideas should be input to the team's thinking.
  - Ask for technical terms or concepts to be explained in simpler words.
  - Ask the expert to draw a picture.
  - Ask the expert to present the data to the team and explain what it means.
  - Ask for the expert to have a segment of the meeting time to teach the other team members key information that would help in the team's work.
  - Ask to hear everyone's reactions to what the expert says.

    "Could we go around the room and each say how these ideas match our own experiences?"

Lack of Focus

Symptoms

- **Floundering or wandering off the path**
  - No one knows what is most important to focus on.
  - Members discuss several topics at the same time.
  - People lose track of what the discussion is about.
  - People say the same things about the same topics that they've said in previous meetings.
  - Discussions never get completed before a new topic gets started.
- **Too much to do**
  - Too many things to work on all at once.
  - So much going on that there is little progress on anything.
- **Too many distractions**
  - People spend more time telling personal stories, joking around, taking phone calls, etc., than on the team's task.

Why it's important to have focus

Teams need a sense of progress and momentum to feel successful and enthusiastic about their work. When the team fails to focus on its work, members can become frustrated, bored, or lose interest, and may even stop doing the work or coming to meetings.

Part of the trouble is that it's very easy to lose focus—there are a lot of factors that can get a team off track!

What you can do

- **Help your team develop and maintain focus** (See p. 151)
- **Help your team narrow its focus when there is too much to do** (See p. 153)
- **Help your team overcome distractions** (See p. 153)

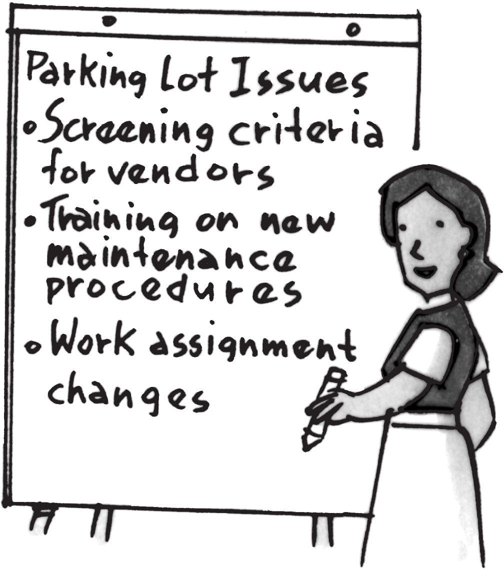
➤ **TIP** *There will always be many issues competing for the team's attention. Revisit your purpose statement periodically to remind yourself about your team's focus.*

Tips on keeping focused

- Make sure your team is clear about its purpose, deadlines, limits, etc. (See Chp. 2)
- Use agendas to keep track of what should and should not be covered in each meeting. Ask that the purpose statement be printed at the top of every agenda. (See Chp. 3, p. 76)
- When the team has been off track for some time, suggest moving back to the task.
  "Where are we in finishing our work today?"
- Suggest that you discuss one issue at a time rather than several simultaneously.
  "Can we finish choosing our measures before looking at data collection forms?"
- Ask if someone can summarize the discussion up to this point.
- Find a way to keep track of issues you want to temporarily set aside.
  - For example, put ideas not related to the topic under discussion on a separate flipchart (sometimes called a "parking lot"). (See p. 152)

Example of a "parking lot" flipchart

During a discussion of changes to a purchasing process, this team kept track of related issues that came up but that they didn't want to deal with immediately. These issues were added to the agenda for the next meeting.



Tips on narrowing focus

- Use data to identify the most important thing to focus on first—look for problems that occur most frequently, have the most impact, or that customers care about most.
- When new issues or opportunities arise, check them against your team's purpose and plans. Will working on that issue contribute to the team's progress?

Tips on overcoming distractions

- Ask that there be an agenda item for personal "check-ins" at the beginning of your meetings (try for no more than 5 minutes). This can help people make the transition from "other work" to "team work."
- If people start telling stories during the meeting, help to bring the focus back to the task at hand.

  "I think we're running out of time for this topic. Could someone recap where we were so we can close the loop?"

Too Much Agreement

Symptoms

- Nobody disagrees.
- Once a position is outlined, everyone focuses on why it's right. No one raises objections.
- No alternatives are offered and different perspectives are quickly dismissed.

Why it's important to have some disagreement

When team members want to get along above all else, the team can fall into "groupthink." Everybody automatically goes along with a proposal even when they secretly disagree. This can lead to bad decisions because …

- Critical information is withheld from the team. People decide their concerns are not relevant.
- Ideas are accepted without careful consideration of their pros and cons.

What you can do

- **Help your team avoid groupthink**
  - Suggest the team brainstorm a list of options before discussing any course of action in detail.
  - Speak up if you have a different point of view.
  - Remind members that all ideas should be thoroughly examined and understood by everyone.
  - Develop a list of criteria and help the group systematically apply the criteria to all the options.
  - Suggest that the team ask a "devil's advocate" to raise objections to a solution.

➤ **TIP** *Once an option is selected, brainstorm everything that could go wrong with that choice. Discuss ways to prevent potential problems and to avoid risks that are identified. Then decide if additional information is needed.*

Uneven Participation

Symptoms

- Some members talk too much.
- Others talk too little.

Why it's important to balance participation

To be successful, teams need input from every member.

- When some members take up too much air-time, others have less opportunity to explain their points of view. People who talk too long can keep a team from building momentum and can make some team members feel excluded from the team's work.
- At the opposite extreme are members who say almost nothing. They may be quiet because they have a hard time breaking into the discussion, or because they need some silence to find the words they want to say. It's important for the team to find ways to invite their input.

What you can do

- **Help to establish the ground rule that it's important to hear from everyone in the group**
- **Speak up when *you* have something to say**
- **Suggest methods for hearing from others in the group**
  - Suggest going around the group in turn so everyone can get a chance to offer a viewpoint.
  - Ask quieter members for their viewpoints.
  - Ask if the team could break into subgroups to discuss some issues, then have the subgroups come back together to share their ideas.
  - Ask that everyone take a few minutes of silent thinking time so that people who find it hard to speak up can have time to organize their thoughts.

Lack of Follow-Through

Symptoms

- Tasks don't get done on time.
- People don't do assignments between meetings.
- People won't volunteer to do tasks.

Why it's important to have follow-through

Teams cannot make good progress without much of the work occurring between team meetings. This means that members must volunteer for tasks and be responsible for completing them. When this doesn't occur, the team bogs down and loses momentum.

What you can do

- **Volunteer for tasks that need to be done and schedule time on your calendar to do the work**
- **Ask for help from your team leader or other team members if you cannot complete a task**
  - Take advantage of being on a team! Your fellow team members might be able to juggle their workloads and responsibilities to help you get done on time.
- **If you don’t have enough time between meetings to do team work, talk to your supervisor or manager**
  - In most cases, team responsibilities are something you have to do in addition to your regular job. If your workload gets overwhelming, it’s worth a try to speak with your manager or supervisor to see if your priorities or responsibilities can be changed temporarily.

CHAPTER 5: ACTION TIPS

- *Do not let group problems fester! The longer you ignore them the worse they will get—guaranteed!*
- *Keep in mind that the purpose of trying to solve group problems is so your team can get its work done. You are not there trying to make everyone get along like best friends! Keep focused on the team's work.*
- *As much as possible, avoid blaming individuals. Think of problems as* ***group*** *issues, not as something that affects only one or two people. Try to think of ways that the whole team can work together to minimize disruptions and conflict, to keep focused on its work, etc.*
- *Learning to deal with group problems is seldom easy, but you can get better at it with some practice. However, don't be afraid to ask for help! Dealing with serious problems may require the intervention of a trained specialist.*
- *The clearer your team is about its purpose, and the more you use data and practice good listening and feedback skills, the better you'll get at preventing problems.*

Index

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IMPROVING THE WAY ORGANIZATIONS RUN

GOAL QPC

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The Problem Solving Memory Jogger™

Seven
Steps
to
Improved
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First Edition

GOAL/QPC

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Seven Steps to Improved Processes

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Printed in the United States of America
First Edition
10 9 8 7 6 5 4 3
ISBN 1-57681-031-3

GOAL QPC

Improving the Way Organizations Run

Acknowledgments

We extend our sincere thanks to the following people for their insights, suggestions, and encouragement throughout the development of this book.

Concept and Content Reviewers

Linda Antonie
American Airlines

Charles F. Boudreau
Quality Dimensions, Inc.

Doug Daetz
Hewlett-Packard Co.

Pamela Dunham
GE Aircraft Engines

Alan H. Field
MicroTouch Systems, Inc.

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Luby Weaver
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John B. Wright
Lifetime Learning, Inc.

How to Use The Problem Solving Memory Jogger™

The Problem Solving Memory Jogger™ is designed for you to use on the job or in the classroom. This book uses a **problem-solving model** based upon a variety of data and knowledge-based tools. The emphasis of this model is on **root cause analysis** and **innovative solutions**.

Use this book as part of a **self-study** program or as a reference before, during, and after **training** to learn the concepts, methods, and basic tools for effective problem solving. Each step in *The Problem Solving Memory Jogger™* details the key concepts and the practical skills that you should master. The book also highlights a **case example** that demonstrates how the tools are used in each step in the process.

You'll also find page references to supporting books that include step-by-step details on tool construction and the team process. The shorthand references in this text are:

Reference	Shorthand
The Creativity Tools Memory Jogger™	CTMJ
The Memory Jogger™ II	MJII
The Memory Jogger™ 9000/2000	MJ9000/2000
The Project Management Memory Jogger™	PMMJ
The Team Memory Jogger™	TMJ

You can also find the information in electronic form on the CD-ROM *The Memory Jogger™ E-Book Series*. It provides the full text for the tools and topics from five of GOAL/QPC's most popular pocket guides (listed above).

What do the different icons mean?

Getting Ready–When you see this runner, expect a brief description of the purpose of a step *(What does this step do?)*, along with the necessary concepts and actions you'll need to be effective in implementing the steps of the problem-solving model. *(What concepts must I understand to do this step?* and *What actions must be taken in this step?)*

Cruising–When you see this runner, expect to find step-by-step instructions or guidelines for a step or tool. *(How do I do it?)*

Finishing the Course–When you see this runner, you are reading the case example that is featured throughout the book.

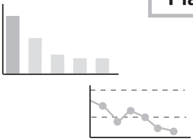
Tips–When you see this figure, you'll get tips on a step, tool use, or team behavior.

Turbo-charging–When you see this icon, you'll get ideas for unique and innovative ways to enhance your team's problem-solving efforts. Get comfortable with the basic steps but when your team is ready, move to a higher level of performance with *How can I turbo-charge this step?*

Snapshot of the 7-Step Model

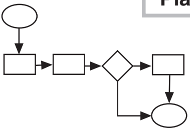
7-Step Model

Plan



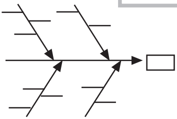
1. Describe the problem

Plan



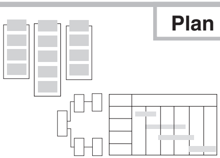
2. Describe the current process

Plan



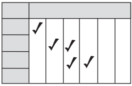
3. Identify the root cause(s)

Plan



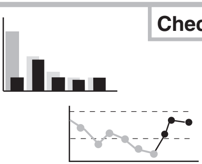
4. Develop a solution and action plan

Do



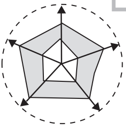
5. Implement the solution

Check



6. Review and evaluate the results

Act



7. Reflect and act on learnings

Contents

Chapter One

Chapter Two

Chapter Three

Plan

Do

Check

Act

Chapter Four

Introduction

Today, virtually every organization is seeking to ensure that their processes provide the highest attainable product and service quality while making the most efficient use of available resources. To meet this challenge, businesses, government agencies, educational institutions, and not-for-profit organizations are integrating a system of practices known collectively as Process Management.

As defined by GOAL/QPC and used in this book, Process Management is "the never-ending quest for improving business processes by *understanding, measuring, innovating, improving* and *managing* how work gets done to accomplish organizational goals." GOAL/QPC's research has identified five distinct elements that comprise an effective process management system. These elements are:

- **Customer Focus** - defining customer requirements and consistently meeting them and delighting the customer by providing exciting dimensions of quality.
- **Benchmarking** - studying best operating practices and using that knowledge to create visions and goals for higher levels of performance.
- **Process Mapping** - creating clean and efficient steps, guidelines, operating procedures, and decision systems for accomplishing the necessary and sufficient work to meet customer needs and exceeding their expectations.
- **Process Measurement** - creating systems to monitor and report on how well actual performance compares with planned performance and using that data to identify problems and successes.
- **Problem Solving** - a systematic methodology for examining the workings of a process to correct performance deficiencies, and to improve processes and attain even higher levels of performance.

As we enter the 21st century, there is a clear trend in organizations to rely on their employees to help manage business processes and reach performance goals and provide value to customers. Their analytical skills help integrate knowledge of customer requirements into the design of lean and effective processes and to measure the performance of these processes. Their skill in using a systematic method for problem solving empowers them to implement corrective measures when problems occur, to continuously improve the performance of their processes, and to standardize and hold the gain once improvements are made.

The Problem Solving Memory Jogger™ gives employees, at all levels, a proven and practical seven-step, problem-solving method that can easily be learned and used to remove barriers to higher levels of performance and, when necessary, to implement corrective measures.

Whatever your performance improvement goal, *The Problem Solving Memory Jogger™* will help.

We wish you well in your quest.

Chapter One

Finding & Solving Problems in Your Processes

Problem solving: an overview

We all have to deal with problems in our lives. At work, problem solving is often focused on processes that need to be improved to exceed customer expectations or to improve the efficiency of operations.

In an organizational sense, problems exist when there is a gap between a current condition (what is) and what must be, should be, or could be. In today's turbulent organizations, the "should be" of today may become tomorrow's "must be."

Individuals, teams, and organizations must quickly meet changing customer needs or adjust to a changing business environment that creates a gap between current capabilities and a desired level of functioning.

Problems are solved most effectively when you take a systematic approach. As organizations strive to attain ever-increasing levels of effectiveness and product quality, they find that systematic problem solving is a core competency that must be mastered throughout the organization.

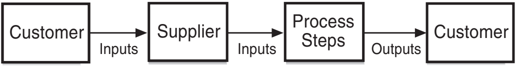
Successful people and successful organizations are not without problems. They simply know how to solve problems and implement effective and lasting corrective measures when they appear.

Work as a process

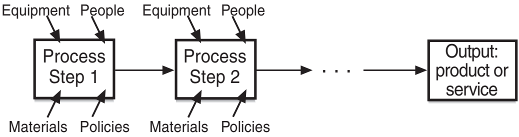
For you and your team to practice effective problem solving, it's important to understand that a process:

- Is the work you do
- Can be broken down into a repeatable sequence of events
- Consists of connected events that lead to predictable results

A process is the set of procedures or patterns of tasks that you do to produce a product or service that is needed by the customers of the process. If you begin with a known customer need or requirement, a process starts with the **supplier**. A supplier is any person, department, or unit that provides you with **inputs** (information, products, services, or materials that you consume or add value to) in order to accomplish your work (produce an **output**). The **customer** is anyone who has a need and receives or benefits from the output of your work.



In the series of process steps that you perform, each step is influenced by many factors (equipment, people, measures, materials, policies, and environment) that can affect the outcome of your work.

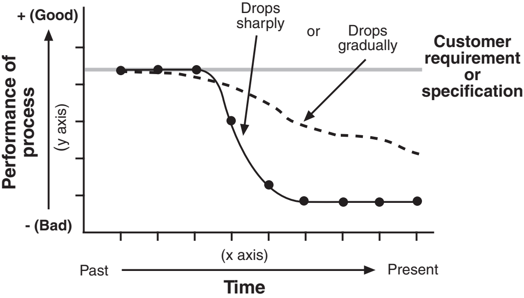


If the process is properly defined (i.e., has a logical sequence of process steps), and the factors work together well, then the outcomes will be good and will satisfy your customers' wants or needs. If any of the factors don't work well together, then the outcomes will not likely satisfy the customer, and the customer may look for another provider for the product or service.

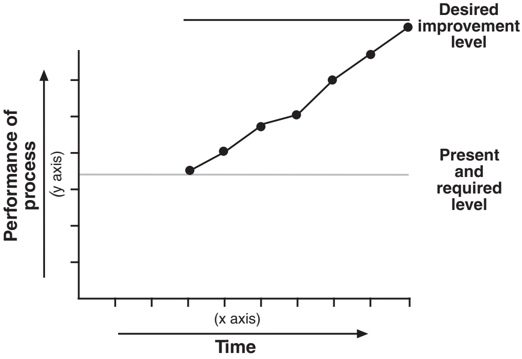
What is problem solving?

A problem exists when there is a gap between the current performance level of a process, product, or service, and the desired performance level. Problem solving, as it's covered in this book, is the systematic investigation of a process to identify the root cause of the gap, and taking corrective action to eliminate the gap and keep it from occurring in the future. To improve a performance gap, you can do any of the following:

- **Fix the process** when it is broken, i.e., it is not meeting the current customer requirement or need (but it did in the past). The gap can occur suddenly or evolve gradually over time.



- **Improve the process** when the organization or your customers will benefit from improving it, even though the process is working adequately.



- **Create a new process** because the old one is no longer adequate, or there is no process in place and one needs to be created to fulfill a requirement or need.

You can solve problems successfully by taking a systematic approach to studying your processes. By using helpful tools and techniques, you can analyze and understand what is going on in your process and identify the most important problem to work on.

It is important that you work on the right problem: one that is important to you, your organization, and your customers. Working on the wrong problem will only waste valuable resources and disappoint your customers.

What is process improvement?

You can keep your customers happy by providing them with the "best" possible product or services. "Best" is defined as meeting the customers' needs and exceeding their expectations.

You can provide the best products or services only by improving the *processes* that produce them—by *process improvement*. You do not improve a process by weeding out the good from the bad once a product or service is produced. To do so would only encourage continued production of bad product and raise the cost of the process.

Instead, process improvement is about improving quality while reducing cost and eliminating waste.

To effect an improvement in a process, it's important to have measures of the process. These measures will indicate how the process is performing relative to your organization's desired or targeted performance levels. These measures will help you to **check** your current performance and to focus your corrective or improvement **actions**.

Process improvement may mean making a process more efficient, less costly, more "capable" of meeting customer requirements or specifications, and/or more consistent and reliable in producing an output that is valuable to the customer.

Why are process measures important?

Process measures are a means of determining the degree to which your process activities and their results are conforming to your plan and to customers' requirements and needs.

Measures are important because they provide data that helps teams to identify and solve problems. Measures are also central to defining a problem, understanding how to solve it, and then informing the team and others in the organization on how well the solution is working toward resolving the problem. In short, measures are important indicators for the health of a process. They help you answer the following questions:

- Is the process performing well?
- Is it meeting the customer need or requirement?
- If not, how far off is it?

There are many measures that will help you understand how your process is performing. For example:

Input measures (measure quality, cost, and conformity to requirements)

- **Information, materials, and/or services that you receive from a supplier.** Defective input from a supplier will adversely affect the overall quality of your output and/or process efficiency.

Process measures (measure different elements within the process)

- **Cycle time**: How much time do various steps in the process take? Are there delays in some steps?
- **Bottlenecks**: What types of bottlenecks are you seeing? How frequently? How long is the delay?
- **Quality**: What types of defects are you seeing in a step?

Outcome Measures (measure the final outcome of the process)

- **Yield**: How many of your products or services out of the total that were made or delivered meet customer requirements?
- **Quality**: Does the product or service meet the customer requirements?
- **Cost**: How much does it cost to produce the product or service and how does the cost compare to your competitor's costs?

- **Customer satisfaction**: How happy are your customers with the product or service?

What is good team-based problem solving for process improvement?

Typically, problem-solving and process-improvement activities involve several disciplines and cut vertically, horizontally, or diagonally across several functional areas. For these reasons, most organizational problem-solving efforts are team-based.

In order to have a high-performing team, make sure everyone understands his or her role and responsibilities in the team. (Guidelines for teams can be found in the book, *The Team Memory Jogger™*.)

Good Teams:

- ✓ Understand work as a process
- ✓ Identify important problems to work on
- ✓ Develop team skills
- ✓ Find the root cause
- ✓ Generate innovative solutions

Key success factors for problem solving

Team Membership: Having the right team members is a critical success factor in participative problem solving. While there is no magic formula for successful teams, here are some questions to consider in forming a problem-solving team:

- Does the team have the right knowledge, skills, and experience?
- Are all perspectives on the issue represented? (i.e., customer, stakeholder)
- Is the size of the team manageable?

- Are temporary members with specialized skills needed?
- Can team members devote the time necessary to work on the project?
- Does the team have a leader?
- Does the team have a healthy mix of experienced and inexperienced problem solvers as members?

Team Environment: The benefits of working in a team environment allow each team member to:

- Contribute ideas based on his or her knowledge and experience
- Think creatively
- Learn by collecting, sharing, and analyzing data
- Develop the interpersonal skills vital to effective teamwork

Collectively, these conditions will allow a team to generate not only more ideas but better ideas that will lead them toward finding better solutions.

Team Commitment: A team that is committed to effective problem solving will take the time to establish clear goals and team procedures, learn how to apply the tools and steps of the 7-Step Model, develop and recruit strong leadership skills, document their work every step of the way, and support one another.

Clear goals and objectives

- Define the problem's boundaries. Which processes are involved? Which are not?
- Put together the right people to solve the problem.
- Establish measures of end results (goal).
- Develop a plan of how the team will accomplish the goal, including appropriate timelines and deadlines.

Knowledge of how to apply the 7-Step Model and the basic tools for problem solving

Some of these tools are:

- The Quality Control Tools (e.g., Run Chart, Pareto Chart, Control Chart, Flowchart, Cause and Effect Diagram)
- The Management and Planning Tools (e.g., Affinity and Tree Diagram)
- The Creativity Tools (e.g., Imaginary Brainstorming, Picture and Word Associations)

Strong, effective, and efficient leadership

- Train, motivate, and guide teams.
- Develop leadership among all members.
- Act as a liaison between the team and others in the organization, especially with management.
- Apply good team meeting skills, which include:
  - Assigning roles and responsibilities
  - Using agendas and keeping to time allocations of each item
  - Soliciting active participation of every team member
  - Promoting active listening, constructive feedback, and clear communication
  - Establishing and living by team ground rules
- For more information on team facilitation guidelines, refer to the pocket guide *Facilitation at a Glance!*

Decision-making procedures

- Use consensus rather than majority vote. It's important that all team members support the decision of the team.

Documentation of the team's work

- Plan and record the project as a team.
- Give periodic team reports to the right people.
- Use the tools to document the team's discussions.
- Share minutes of team meetings as appropriate.

Visible, committed sponsorship and recognition

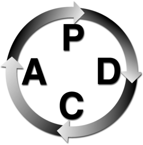
- Nurture a supportive and creative environment.
- Give the team a sense of ownership of the problem.
- Provide guidance and parameters for the team to work within.
- Give both verbal and active commitment, i.e., "walk the talk."
- Work to build trust among team members, managers, and others in the organization.
- Provide needed resources, including time, meeting space, and materials.
- Recognize individuals for their contributions toward the team's success.

Chapter Two

Using a Systematic Model to Solve Your Problems

An effective and systematic approach to problem solving is to use the 7-Step Model, which provides a repeatable set of steps, actions, and tools as part of the Plan-Do-Check-Act Cycle.

What is the power of the Plan-Do-Check-Act (PDCA) Cycle?



The PDCA Cycle was a fundamental component of Dr. W. Edwards Deming's pioneering work in quality management. He saw work as a never-ending improvement process to achieve better quality products and services and to improve the processes that make and deliver them. The PDCA Cycle, or "Deming Cycle" as it is often called, consists of four stages: Plan, Do, Check, Act.

The PDCA Cycle is a powerful approach for problem solving. It is an excellent foundation for helping teams to:

- Systematically identify and understand a problem or issue and its root cause(s) rather than the symptoms
- Generate ideas and develop an effective plan to solve the problem
- Ensure that the current problem stays fixed and then move on to other problems

The PDCA Cycle can be compared to the scientific method many of us learned in high school or college science classes, i.e., create a hypothesis, perform an experiment, analyze the results, and draw conclusions.

The PDCA Cycle provides, as does the scientific method, the principles and procedures for the systematic pursuit of knowledge. Using the PDCA Cycle will provide teams with the knowledge they need to fix, improve, or create any product, service, or work process.

The steps of the PDCA Cycle are:

PLAN…	Plan a change or a test aimed at improvement, once the root cause of the problem is determined.
DO…	Carry out the change or the test, preferably in a pilot or on a small scale.
CHECK…	Check to see if the desired result was achieved, what or if anything went wrong, and what was learned.
ACT…	Adopt the change if the desired result was achieved. If the results are not as desired, repeat the cycle using knowledge accumulated from the previous cycle.

In applying the PDCA Cycle to problem solving and process improvement, it is assumed that:

- A process exists
- Goals, objectives, and requirements for the inputs, process steps, and outputs have been established
- Key performance measures have been established and applied

The problem-solving process normally begins at the **Check** stage where actual performance is measured and compared with performance requirements. When the results indicate a gap between the measure and the required performance, and the gap is severe enough to cause you to **Act** (to repeat the process), you are ready to begin applying the 7-Step Model for problem solving.

Another of Deming's major contributions was the Control Chart. (See Appendix C for detailed information on this tool.) The Control Chart is very helpful in process improvement because it identifies what problems are due to common causes (sources of random variation that are inherent in the normal operation of the process), and which problems are due to special causes (unique events that are not associated with the normal operation of the process).

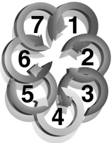
Deming had three important lessons on variation in a process:

1. Fix special causes first, then concentrate on common causes.

2. Always distinguish between what the customer requires from your process, i.e., the specification limits, and what the process actually produces when it's "in control," i.e., within control limits.

3. It is almost always beneficial to the process owner and process customer if you reduce variation in your process. Reducing this variation will help you to achieve six sigma quality, which means 3.4 defects per one million outputs.

What is the 7-Step Model for problem solving?



While the PDCA Cycle maps out a fundamental approach to understanding and resolving problems, teams often need more detail to guide them in their problem-solving effort. Team members often ask, "What do I do in the **Plan** stage?" "What tools are most helpful in understanding the problem and getting at the root causes?" or "What is the best solution and how do I implement it?"

Each step in the 7-Step Model explains what must be done and the typical tool(s) used. These steps are based on the PDCA Cycle.

The steps and key tasks in the 7-Step Model are defined in the table on pages 16–18. The table also recommends which tools are most appropriate for each step of the model. Because of space constraints, only a few of the recommended tools are described in this book. For detailed instructions on constructing a tool, consult the following pocket guides:

- *The Memory Jogger™ II* (Affinity Diagram, Brainstorming, Cause and Effect Diagram, Control Chart, Flowchart, Gantt Chart, Matrix Diagram, Pareto Chart, Process Decision Program Chart, Radar Chart, Run Chart, Tree Diagram)
- *The Creativity Tools Memory Jogger™* (Classic Brainstorming and Imaginary Brainstorming)
- *The Project Management Memory Jogger™* (Project or Action Plan)

Why is this problem-solving model better and different from other models?

Teams have often learned the tools apart from the context of a problem-solving situation. The 7-Step Model presented in this book provides this context. The presentation of this model provides teams with a step-by-step approach to problem solving, includes sub-steps with recommended tools for doing each of the seven steps, and illustrates a case example that is introduced throughout each step and tool application. As your team follows the steps in the model, you'll discover that:

- Each step is specific in recommending actions that need to be accomplished.
- In some places, there are checklists to help you navigate through the step, making it easier to know what you need to do, what you've done, and what you still need to do.
- Each step focuses on the most basic tool(s) required to accomplish the step, including helpful tips that will enhance the team's construction and interpretation of the tools.
- When a team wants or is ready to expand beyond the basic tools, there is the option of integrating more of the management and planning tools, the creativity tools, or other helpful tips. Check out "How do I turbo-charge this step?" to find out more.

A Quick Guide to the 7-Step Model: Steps, Key Tasks, and Tools

Step	Key Tasks	Primary Tools
	Plan	
1. Describe the problem.	• Look for changes in important business performance measures. • Assemble and support the right team. • Narrow down the project focus. • Write a final problem statement.	• Control Chart • Pareto Chart • Run Chart
2. Describe the current process.	• Create a Flowchart of the current process. • Validate the Flowchart and the performance measures with the owners, users, and customers of the current process.	• Flowchart
3. Identify and verify the root cause(s).	• Construct the Cause & Effect Diagram. • Review the Cause & Effect Diagram. • Determine if more data will clarify the problem. • Select the root cause(s). • Verify the root cause(s).	• Classic Brainstorming • Cause & Effect Diagram • Matrix Diagram

A Quick Guide to the 7-Step Model, continued

Step	Key Tasks	Primary Tools
Plan *(continued)*		
4. Develop a solution and action plan.	• Generate potential solutions. • Rank potential solutions; select the best solution. • Generate possible tasks for the solution. • Construct a detailed action plan.	• Affinity Diagram • Gantt Chart • Decision Matrix or Prioritization Matrices • Process Decision Program Chart • Responsibility Matrix • Tree Diagram
Do		
5. Implement the solution.	• Communicate the plan. • Meet regularly to share information on how the implementation is going.	• Action Plan • Selected measurement tools
Check		
6. Review and evaluate.	• Review the results of the change. • Revise the process as necessary. • Standardize the improvement. • Continue to monitor the process for changes.	• Control Chart • Pareto Chart • Run Chart

Continued on next page

A Quick Guide to the 7-Step Model, continued

Step	Key Tasks	Primary Tools
Act		
7. Reflect and act on learnings.	• Assess the problem-solving process the team used and the results achieved; recommend changes, if needed. • Continue the improvement process where needed; standardize where possible. • Celebrate success.	• Radar Chart

Note: While there are many more tools available than are listed in the table, the purpose of the 7-Step Model is to start with the basics for a team just getting started. Look for the sections called "How do I turbo-charge this step?" in Chapter 3 to get more out of your problem-solving effort.

The seven steps of the model are presented in more detail with a case example in Chapter 3.

Chapter Three

Implementing the 7-Step Problem-Solving Model

This model uses seven discrete steps that are based on the Plan-Do-Check-Act Cycle for problem solving. It helps teams to:

- Systematically solve a problem
- Understand and communicate the problem
- Identify when additional data is needed
- Synthesize data into a visual form that can be analyzed
- Use tools to interpret data and make conclusions
- Develop and implement solutions to the problem
- Monitor the problem for ongoing effectiveness
- Learn from the team's problem-solving experience

Plan

Page

Do

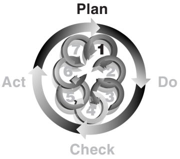
Check

Act

Step 1

Describe the Problem:

Select the problem that will be addressed first (or next) and describe it clearly.



What does this step do?

Helps teams to focus on the most important problem rather than a trivial one when resources and time are limited. Teams can then begin to understand and describe the problem and improvement opportunity.

What concepts must I understand to do this step?

Importance of Understanding the Problem

- **Focus on the right problem.** With limited time and resources, it is essential to focus on a problem that is most important to the customer, the team, and the organization.
- **Break the problem into manageable pieces.** This prevents a team from feeling overwhelmed by the larger problem and helps the team identify the pieces that it can control and change.
- **Gain more knowledge to better define the problem.** This ensures the team keeps all its efforts focused on solving the right problem with the right people.
- **Describe the problem as the gap between what "is" and what it should or could be.**

Importance of Gathering Data and Information

Data can help teams:

- **Reveal a problem.** Teams can't fix a problem they don't know about.
- **Describe a problem.** When teams understand what the problem is, they can fix the problem rather than just addressing the symptom.
- **Monitor and control a problem.** Teams can make sure that what they fix or improve stays that way.
- **Prevent a problem.** When there is a consistent trend or cycle in the data, a team can take action to reduce or eliminate the undesired trend or cycle in the process before it becomes critical and/or apparent to the customer. It's always easier to prevent a problem than to have to correct it.

Types of Data

There are two types of data to measure process performance: variable data and attribute data. It is important to know which type of data you have since it helps determine which tool to use.

- **Variable data:** data is measured and plotted on a continuous scale over time, e.g., temperature, cost figures, times, strength, pH levels. Use Run Charts, Histograms, Scatter Diagrams, and Variable Control Charts to illustrate this data.
- **Attribute data:** data is counted and plotted as discrete events for a specified period of time, based on some characteristic, e.g., types of shipping errors, types of customer complaints, reasons for downtime. Use Check Sheets, Pareto Charts, and Attribute Control Charts for this type of data.

What actions must be taken in this step?

- **Identify** important **business and process measures** that focus on the **customer.**
- Identify what **type of data** is needed to define the problem.
- **Arrange data** into a form that can be **analyzed** for meaning. Two good choices are the Run Chart and Pareto Chart.
- **Write a problem statement** that describes the problem as a gap between the present condition (what is) and the required or desired condition (what should be).

How do I do it?

1. **Look for changes in important business and process performance measures.**
   a) Monitor important processes and their key business performance measures.
      - Measures must:
        - Be objectively measured with data that reflect the process.
        - Support major business objectives.
        - Be directly related to a customer need or financial need of the organization.
      - See the chart on p. 25 for examples of measures.
      - For more ideas on measures, see Types of Measures in Appendix A.
      - Depending on the organizational improvement structure, this step may be done by a steering team, management team, or problem-solving work team.
      - If the business performance measures already exist, monitor them using graphics and charts.

Whenever possible, start with data. The discovery and definition of a problem through data collection and analysis reduces the power of opinions and ill-informed decisions.

Typically a team uses data to determine:
1) Where the problem is and is not occurring;
2) When the problem began; and
3) What the extent of the problem is.

Sometimes the gap between the present and desired condition is so large that emergency actions are needed. These actions may not support the identification of root causes and solutions but can limit the impact of the problem. These actions may include: 1) Recalling product if it threatens someone's safety and health; 2) Quarantining finished product; 3) Stopping further production.

b) Chart the current business and process performance measure(s).

- Use a **Run Chart** or a **Control Chart** to plot variable data. These charts show you how the measure performs over time. (For more information, consult the *MJII*, p. 141 for the Run Chart and Appendix C in this book for the Control Chart.)
  - Data graphed over time helps teams to see if the process they are studying is steady, improving, or getting worse.

  - If the process is performing differently than expected, then a team has cause to question this. The team should determine why it has changed and the extent it has changed.
  - Use a Control Chart to distinguish between common cause variation (naturally occurring within the process) and special cause variation (a unique cause not naturally occurring within the process).
- In addition to the Run Chart or a Control Chart, a **Pareto Chart** can be used to chart the performance of the business and/or process measure and to prioritize business issues that need to be addressed. Use a Pareto Chart to visually display attribute data. (See Pareto Chart, *MJII*, p. 95.)
  - A Pareto Chart helps a team identify the biggest problem or need for improvement by taking a complex issue and breaking it down into categories of different problems that are occurring. It is used to further prioritize problem areas, categorize customer complaints, defect types, etc.
  - The Pareto Chart is based on the Pareto principle: 20% of the sources cause 80% of the problems.
  - Identify the category that has the highest frequency of occurrence, e.g., the highest cost or highest negative impact, and consider focusing there.

c) Examine the measures and use significant changes in them as signs of potential problems for a team to resolve.

d) Create a draft statement of the problem.

Examples of Key Business Performance Measures

Problem	Measured objectively with data		Supports major business objectives	Directly related to customer need or company finances
	Measure	Chart		
HOSPITAL: Patients waiting too long to see the emergency room physician	Wait time from patient logs	Run, Control, or Histogram	Relates to quality of patient care	Impacts finances if patients go to another hospital
	Reasons for long wait time	Pareto		
PLANT: Manufacturing not meeting production targets	Yields (% of quality)	Run or Control	Efficiency and quality of products	Customers' orders not filled Company loses customers to competitors Lowers sales
	Machine downtime (# of times machine breaks and duration)	Run or Histogram		
	Reasons for downtime	Pareto		

This is the beginning of a case that illustrates the use of the 7-Step Model. The case continues throughout the steps in this chapter.

"The Case of the Missing Deadline"

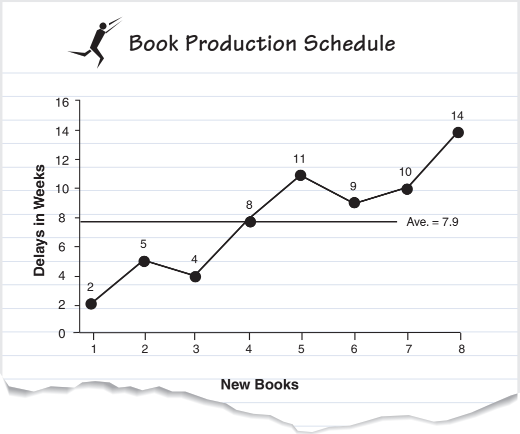
The Atlantic Book Company (ABC) is a 145-person publishing firm. ABC's success in the last 20 years has been in writing and publishing "how-to" books. More recently, ABC's merger with another publisher has enabled the company to expand into new markets.

Growth has come at a cost, however. As the company has grown, it is increasingly difficult to finish new products on schedule. Jeremy, ABC's New Product Development Manager, was well aware that deadlines were missed more often than met.

Not only was it difficult for Jeremy's new product development staff to meet the deadlines, but morale was suffering too. The latest employee survey showed a 15% drop in job satisfaction. The decline was directly related to work pressure and having to work longer hours.

Jeremy also knew that on-time delivery of new products was an important measure of the health of the business. He decided it was time to solve this problem. Using the data from the Run Chart, Jeremy composed the following problem statement:

"For the past two years, and the last eight projects, book production has been late on average by 7.9 weeks."



2. Assemble and support the right team.

- If a steering team identified the problem area to address, another team should be chartered to further study and solve the problem. (Also see *PMMJ*, pp. 26-27.)
- If a team has already been formed and identified the problem, verify that the team has the right members.
- Consider including suppliers and customers of the process as team members.
- Also include people who will satisfy the team's needs.
- Ask team members if anyone is missing or needed, but remember to keep the team small and manageable, i.e., 5–8 people.

Putting Together an Effective Team

Skills	Does someone do something unique that is a required part of the process? *Examples:* precision welder, secretary, lab technician, or facilitator.
Knowledge	Is there someone who has essential pieces of information about the problem or process? *Examples:* research chemist, nurse, customer and/or supplier, service manager.
Approval	Is there someone whose "OK" is required before a likely solution can be implemented? *Examples:* purchasing manager, finance manager, general manager, CEO.
Acceptance	Are there individuals who can effectively block implementation of a likely solution if it is not acceptable to them? *Examples:* process owner, supervisor, worker, or sales representative.

The ABC Problem-Solving Team

- Jeremy, Manager of New Product Development (needed for Approval, Knowledge)
- Felicia, Lead Editor (needed for Skills, Knowledge)
- Rich, Customer Representative (needed for Acceptance)
- Lani, Primary Writer (needed for Skills, Knowledge)
- Stephano, Copy Layout (needed for Skills)

At each team meeting, Rich took notes and documented the key ideas that were presented so the team could develop an ongoing storyboard to be posted outside the lunchroom. (Storyboards are discussed in Chapter 4.)

3. **Narrow down the project focus.**

   a) Look for any other data opportunities to further understand and clarify the problem.

   - Is there a different process measure that should be studied?
   - Is there additional data that would help you understand the largest bar on the Pareto Chart?
   - Do you need to create a new Run Chart on a critical measure?
   - Would it be helpful to talk to customers? Suppliers?

Customers' input is invaluable! Their insights to the problem may change what you choose to measure and how you measure it in the process. Understanding your customers' needs can influence the type of solution you later put into place.

Sometimes you can narrow the scope of the original problem, depending on the knowledge of your team members and the data that you've collected. Keep the scope of the problem within your team's:

- Area of control or influence
- Budget
- Schedule for implementing a solution

b) As a team, look at the data gathered so far. Begin to ask, "What's wrong?" "What's not working?" List all potential issues, problems, and opportunities.

c) Identify the issue to focus on. Consider these questions when selecting the issue:

   – What issue appears to be the most important one in need of changing or improving? Look at the Run Chart or Pareto Chart.

   – Is that issue the most important one to the customer? The team? The organization?

   – Does the team have control over the part of the process that needs to be changed?

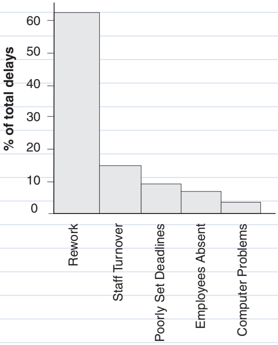
   – Will the necessary resources be available to address this problem?

ABC Team Narrows Down the Project Focus

The team members decided they had to narrow the focus of the problem before they could find a possible solution. They collected data on the past eight projects by talking with other employees, looking at past records, and studying time logs.

After reviewing this data, the team listed possible reasons for the delays. Then the team collected data from project history files on how often each type of delay had occurred. With this data, the team constructed a Pareto Chart to show the frequency of delays.

Reasons for Project Delays



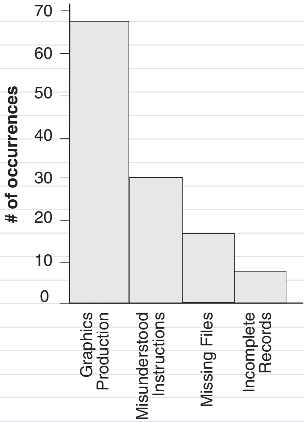
%	62	15	10	8	4

The Pareto Chart showed that more than two-thirds of the delays were caused by rework.

ABC Team Narrows Down the Project Focus, continued

The team dug a little deeper by reviewing work assignment sheets and time logs for the last eight projects completed. Using data from that search, the team named the reasons why projects were delayed and created a second Pareto Chart that showed where the greatest number of delays were occurring.

Reasons for Project Delays



#	68	30	17	8

Based on the data, the team concluded that the leading contributor to project delays was related to graphics production (the tallest bar).

4. **Write a final problem statement.**
   - Write a clear and concise statement of the problem to be addressed by the team.
   - A good problem statement will include the four components shown in the table below.

Components of a Good Problem Statement

1. Direction	What do you want to do to the performance level of the process, *e.g., increase, decrease, cut back, improve, expand, develop, remove, reduce, lower, eliminate, shorten, extend.*
2. Business Measure	The key measure for the process under study, *e.g., errors, mistakes, breakdowns, yields, availability, turnaround time, timeliness, wait time, accuracy, cycle time.*
3. Performance Measure	The current numeric performance value of the business measure.
4. Process Name	The process under study.

ABC Team's Final Problem Statement

"Reduce the large number of graphics needing rework in the new product development process so that book production schedules can be met on time."

How can I turbo-charge this step?

The key to a successful problem-solving effort is to get a team off to a good start with the right people working on the right problem. Consider these other approaches to identifying and defining the *right* problem.

Affinity Diagram and Interrelationship Digraph

(MJII, p. 12 and 76.)

1. Start by talking to the customers, suppliers, or staff and workers. Identify their issues and organize them using the Affinity Diagram. This method truly focuses on a customer-identified concern!
2. Identify the driver of these themed groupings using the Interrelationship Digraph.
3. Identify a key business performance measure related to the driver.
4. Construct a Run Chart or Control Chart on the measure. Construct a Pareto Chart on the identified types of concerns/issues.

Problem Reformulation Tool *(CTMJ, p. 97.)*

If a team has trouble identifying the problem, this tool can help a team visualize the problem in a new way.

1. Using pictures, questions, and criteria, identify the components of the system (process) in order to identify new approaches to focusing on the right problem and then solving it.
2. Look at how the components affect the system and at the interrelationships between the components.

3. After writing new statements of how the components or relationships relate back to the original problem, prioritize and select one.
4. Identify a measure on this new problem statement and evaluate it for further study.

Purpose Hierarchy Tool *(CTMJ, p. 119.)*

This tool identifies the full range of possible purposes of an improvement effort and then focuses in on the one that fits the needs of the customer and available resources.

1. Brainstorm a list of purpose statements that begin with the word "to" and have an action (verb) and an object of that action.
2. Code each statement as to its level of difficulty.

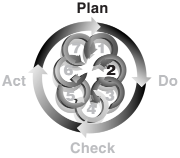
   S = simple
   SM = simple to medium
   M = medium
   MC = medium to complex
   C = complex

3. Order the statements from simple to complex and then select the focus purpose by mapping the statements against applicable criteria.

Step 2

Describe the Current Process:

Describe the current
process surrounding
the improvement opportunity.



What does this step do?

Helps a team to understand work as a process and to identify where in the process the problem occurs.

What concepts must I understand to do this step?

Customer and Supplier Relationships

Each step in a process creates relationships in which people depend on each other to get work done. Each process step depends on one or more suppliers to provide products, materials, services, and/or information that are:

- Reliable
- Defect or error free
- On time
- Complete

In exchange, at each process step the customer provides suppliers with:

- Requirements that are clearly stated
- Timely feedback when needs are not being met

Process Documentation May Be Outdated

Teams need to understand the process they are trying to improve. Oftentimes, a current and detailed Flowchart doesn't exist. If the process has never been documented or the existing Flowchart is outdated, the team will either need to create a Flowchart or update the old one.

Every Process is a System

It's important for everyone in the process to look at and treat it as a system of connected pieces. If you change even one part of the system, it will always affect how the whole system works (or doesn't work).

What actions must be taken in this step?

- **Construct, update,** and/or **interpret** a **Flowchart** to describe and study work as a process.
- **Identify** the **value, time, and cost** added **for each step** in the process.

How do I do it?

1. **Create a Flowchart of the current process.**
    - Use a Flowchart to show all of the tasks and decisions involved in implementing the current process. (See *MJII*, pp. 56–62.)
    - Use symbols to show the flow of actions and decisions in a process from start to end.
    - List all of the steps of the process **as they are currently done**. Keep the level of detail as simple as possible. If necessary, you can always add more detailed steps later.

Flowchart Symbols	
Oval ⬭	Shows the materials, information, or action (inputs) that start the process, and the results (output) at the end of the process.
Box □	Shows an activity performed in the process. Although multiple arrows may come into each box, usually only one arrow leaves each box.
Diamond ◇	Shows those points in the process where a yes/no question is being asked or a decision is required.
Circle with Letter or Number Ⓐ	Identifies a break in the Flowchart and is continued elsewhere on the same page or another page.
Arrow →	Shows the flow of the process.

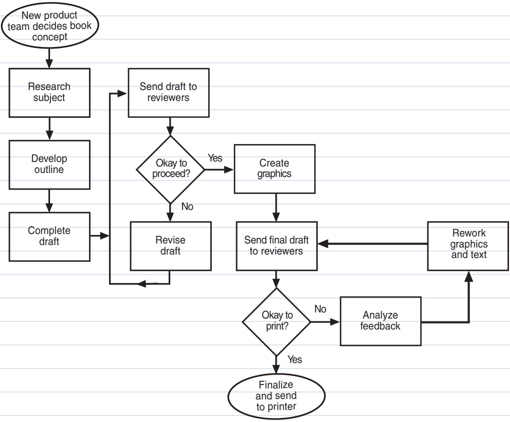
Unless you're using flowcharting software, write each step on a Post-it™ Note. The steps can then be easily sequenced and rearranged.

ABC Team Flowcharts the Process

Lani, the main writer, and Felicia, the lead editor, said that the current process wasn't clear to them.

Stephano said it seemed like projects were getting more complex, and paperwork and files were getting lost as they were shuttled between steps and people in the process.

The team created a Flowchart of the entire process to make sense of what was really happening.



2. **Validate the Flowchart and the performance measures with the owners, users, and customers of the current process.**
    - Before teams can improve a process, they need to understand it. The people who have this understanding are those who work on some part of the process or who use the information, products, or services that are produced by it.

Check for . . .	By asking . . .
Completeness	Does the Flowchart show all of the critical tasks and decision points?
Accuracy	Do the words in the Flowchart clearly describe what's happening at each step and decision point? Are all of the connections drawn as they actually happen, especially flowing from decision points?
Time spent*	What's the range of time that it takes to complete each task or to make each decision?
Overall process measures*	How does the person responsible for the overall process measure its success? How does the customer of the process measure its success? Are the measures objective (based on facts) or subjective (based on opinions)?
Sub-step measures*	How does the person responsible for each sub-step measure its success? How does the customer of each sub-step measure its success? Are the measures objective (based on facts) or subjective (based on opinions)?

Continued on next page

Check for . . .	By asking . . .
Bottlenecks and delays*	Are there delays because the criteria for making decisions are unclear? Are there inspection points where a lot of products and services are rejected or diverted?
Responsibilities	Who measures, improves, and provides information about each step? Is there one person ultimately responsible for each step or is it a shared responsibility?
Quality problems*	Are there any recorded customer complaints about a particular step in the process? Are there any steps that are reworking products, services, or information because they don't meet customer needs?
*Any of these categories can be used to identify areas to work on in your organization's continuous improvement efforts.	

- Confirm the accuracy of the process as it is drawn in the Flowchart and the time estimates for each step by letting the process run untouched.
- Identify the value, time, and cost added for each step in the process.

A step adds time and/or cost when:

- A product or service needs to be inspected.
- A product can't move further in the process because a decision hasn't been made, information hasn't been provided, or related process steps haven't been finished.
- Anything is reworked.
- A product moves anywhere other than the next step in the process.

A step adds value when:

- It makes a product more useful to the customer.
- A customer would be willing to pay for the activity in that step.
- It is required to make the product function properly when used by the customer.

ABC Team Validates Flowchart and Performance Measures of Current Process

Team members validated the Flowchart by reviewing it with coworkers, customers, and suppliers. (They used the same criteria as those listed in the table on pages 40 and 41.) They all agreed that the Flowchart was on target.

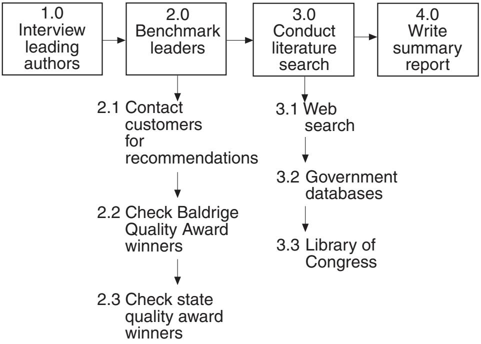
How can I turbo-charge this step?

Top-down Flowchart *(MJII, p. 60.)*

If team members need a deeper look at one or more steps within the process, they can use a Top-down Flowchart. This enables teams to examine in greater detail what activities and decisions take place while performing a step. Follow these instructions to create a Top-down Flowchart:

1. Construct a Macro Flowchart of the major steps and decisions in your process. (Use the symbols shown on page 38.)
2. Assign a number to each step.
3. For each major step, list the sub-steps and their supporting sub-steps. Use a numbered outline system to show the order and hierarchy of the sub-steps.
4. Review the list of sub-steps to identify ways to simplify the process and eliminate bottlenecks and delays.

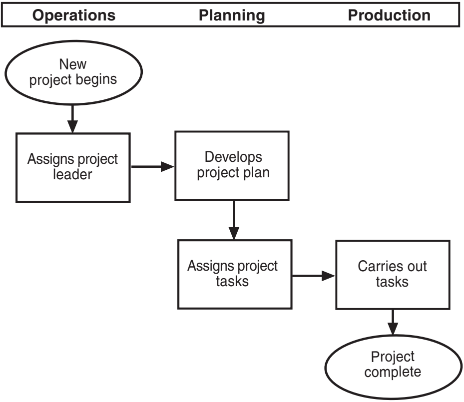
Research Subject Area



Deployment Flowchart *(MJII, p. 61.)*

Use a Deployment Flowchart to clarify roles and responsibilities, track accountability, and determine if the most appropriate staff resources are being used to perform the steps. Follow these instructions to create a Deployment Flowchart:

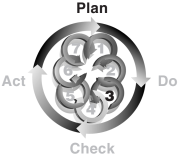
1. List the names of the individuals or departments that perform different tasks in the process across the top of a sheet of paper or flipchart paper.
2. Using a Macro Flowchart of the major steps and decisions in your process, place each action step (box) and decision point (diamond) below the name of the individual or department that performs the task or makes the decision.



Step 3

Identify and Verify the Root Cause(s):

Describe all of the possible causes of the problem and agree on the root cause(s).



What does this step do?

Helps teams identify all the possible causes contributing to the problem and agree on the root causes in order to reduce or eliminate them.

What concepts must I understand to do this step?

Relationship of Cause and Effect

To get at the heart of a problem, teams need to identify all the possible causes of some effect (the problem). Causes are usually attributed to variation in how work gets done. Variation can occur in materials, equipment, and methods, or in the way people do their jobs.

- Variation can occur in one or more process steps.
- The more variation that occurs, the more the effect is influenced and deviates from the desired output.
- To solve a problem, a team needs to identify the source of variation before taking corrective action.
- Sources of variation can be grouped into two major classes:
  - **Common cause** is a source of variation that is always present; part of the random variation inherent in the process itself. Its origin can usually be traced to an element of the process that only management can correct.

  - **Special cause** is a source that is intermittent, localized, seasonal, unpredictable, unstable. Its origin can usually be traced to an element of the system that can be corrected locally, that is, an employee or operator may be able to correct a special cause.

Root Cause Analysis

Root cause analysis is a process of tracking down the sources of variation to identify the key sources that are causing the problem. These root causes, when eliminated or changed, will make the biggest impact toward solving the problem.

- Root cause analysis involves creative thought, data collection, analysis, and objective reasoning.
- Problem-solving teams are most effective when they use a standard approach to identifying root causes.

What actions must be taken in this step?

- **Identify** all possible **causes** of the problem**.**
- Construct a **Cause and Effect Diagram.**
- **Select** the **root cause(s).**
- **Verify** the root cause(s) **with data**.

How do I do it?

1. **Construct the Cause & Effect Diagram.**
   - A Cause and Effect Diagram helps teams to create a picture of the possible causes of a problem, understand how the causes are related, and think about why the problem occurs and where it's occurring.

   a) Using flipchart or butcher paper, write the problem statement on the right-hand side of the paper and draw a box around it. Also draw a long line with a large arrow pointing to it. Make sure everyone on the team agrees on the wording of the problem statement. Add as much information as possible on the "what," "where," "when," and "how much" of the problem.

b) Develop a list of factors that could be causing or contributing to the problem.

- Ask, "What are all the possible causes of the problem?"
- Record the answers on Post-it™ Notes or cards.

c) Select the major cause categories that are appropriate for the team's diagram. There are two types of categories.

- **Major Cause Categories** (Also known as Dispersion Analysis Type. See *MJII*, p. 23.)

  These are standard categories that are generic to most problems. Use either the 4 M's or 4 P's or a combination of them to develop your major cause categories.

  – The 4 M's: Machines, Methods, Materials, Manpower/People.

  – The 4 P's: Policies, Procedures, People, Plant/Equipment.

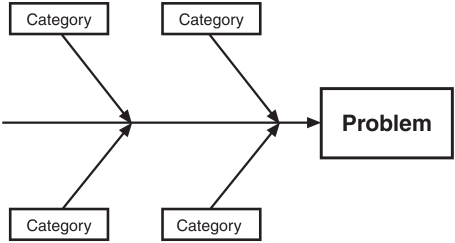
- **Major Process Steps** (Also known as Process Classification Type. See *MJII*, p. 24.)

  These are the major steps of the process in which the problem is occurring. A team can review the Flowchart of the process to determine the key steps.

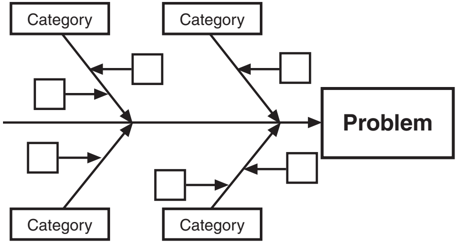
There is no perfect set or number of categories. Select the categories that best fit the team's situation and needs.

The Affinity Diagram can be useful for teams who are having trouble determining the most appropriate major cause categories. Basic instructions for the Affinity Diagram are: a) Brainstorm 10–20 causes; b) Sort the causes into related groupings; c) Create header cards and use them as the major cause categories on the Cause and Effect Diagram.

- Write the major cause categories (or major process steps) on the flipchart paper. Draw a box around each category and connect it with a line and arrow that points toward the line extending out from the problem statement.



d) Place the Post-it™ Notes or cards of possible causes in the appropriate cause categories of the diagram.



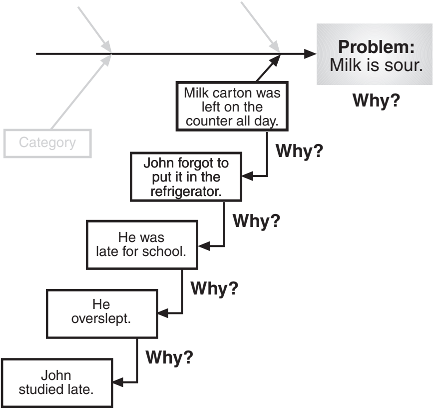
A cause may be placed in as many categories as it seems to fit.

e) Create the next levels of causes.

- For each cause listed on the diagram, ask "Why does this happen?" For each response, repeat the same question and write down the next response. Each successive answer is another possible cause.

- List the team's responses as branches off of the major causes. The placement of connecting lines shows the logical relationship of each response to the one that preceded it.

- Continue to question "Why?" for each cause until the team decides it has enough information to identify the root cause.



Two guidelines for knowing when to stop asking "Why?" are: 1) The team has asked "Why?" to five levels of detail, and 2) The cause is controlled by more than one level of management removed from the team.

The ABC Team Constructs the Cause & Effect Diagram

The team's ideas for why so many of the graphics were reworked are shown on the Post-it™ Notes below.

Little direction on creating graphics

Authors don't convey design ideas well

Computers often crash

Graphics' quality suffers with deadline pressure

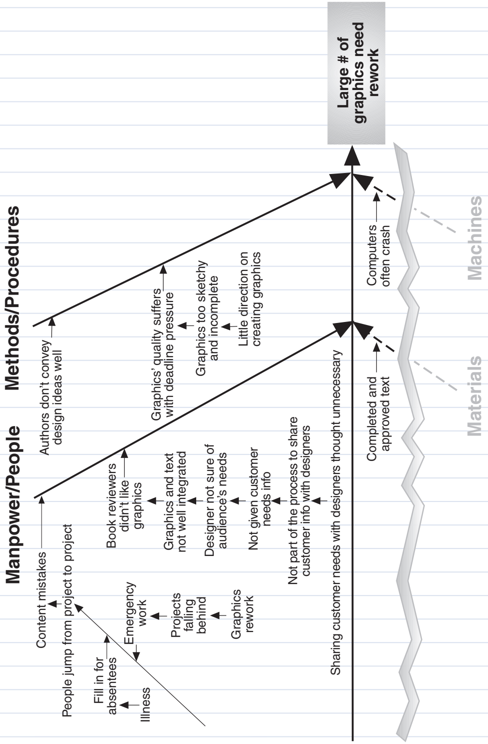
Content mistakes

Graphics too sketchy and incomplete

Book reviewers didn't like the graphics

The ABC Team Constructs the Cause & Effect Diagram

Part of the ABC team's Cause & Effect Diagram is shown below.



2. **Review the Cause & Effect Diagram.**

- Use the checklist below to review the accuracy and completeness of the team's diagram.

Ask:	If you answer no, then . . .
Is the problem (effect) correctly stated? Does it include the name of the process?	• Rewrite the problem statement. Compare the statement written in Step 1 and include any new information gathered.
Have you listed all the potential causes?	• Ask others who also know the process to identify possible causes.
Are all the brainstormed causes categorized?	• If you have trouble fitting a brainstormed cause into a category, add another category called "Other" and place the cause there.
Have you identified solutions instead of causes?	• Save these on a list of possible solutions for later. For now, focus only on identifying causes.
Do the causes relate to the issue?	• Have the team reread the problem statement (effect) again. So as not to lose any information, place any unrelated items in a "parking lot" list to address later.
Is the diagram complete and understandable?	• Make sure every category has detail on it. • Explain any jargon. • Make sure all the causes, as they are written in the diagram, are clearly understood so that their meaning can be recalled later by any team member.

3. **Determine if more data will clarify the problem.**
   - Many of the causes identified by team members are known causes, while others may be informed guesses. Whenever possible, validate these guesses by collecting and analyzing data.
   - Use the tool that will best illustrate the type of data you plan to collect.

Tool	Use it to . . .	MJII page
Check Sheet/ Pareto Chart	• Validate how frequently a cause occurs.	31/95
Control Chart	• Determine if the process where the cause occurs is stable and predictable. • Identify when special cause variations occur.	36
Histogram	• Show the centering and variation of the process due to a cause.	66
Pareto Chart	• Focus attention on the problem areas that have the greatest potential for improvement.	95
Process Capability	• Determine if a process is consistently producing outputs (products/services) that meet customer requirements.	132
Run Chart	• See how the process performs over time due to a cause. Also, to find trends, cycles, or shifts that may occur related to an identified cause.	141
Scatter Diagram	• Determine relationships between multiple causes (variables) and how they influence the effect.	145

4. **Select the root cause(s).**

a) Identify likely candidates for the root cause(s) by one or more of the following actions:

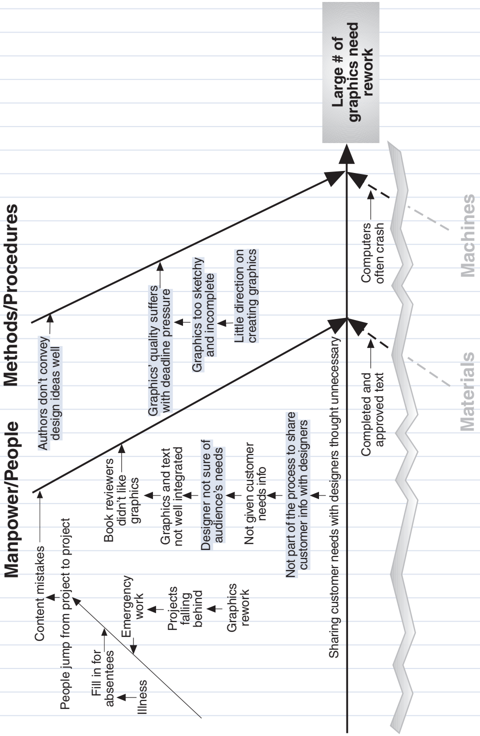
- Look for causes that appear repeatedly within or across major cause or process categories.
- Look for changes and other sources of variation in the process or the environment.
- Use consensus decision-making methods such as Nominal Group Technique or Multivoting. (See *MJII*, p. 91 and 93, respectively.)
- Use collected data that substantiates a potential root cause.
- Use discussion and logic to convincingly explain how a cause is creating the problem.

b) Select the root cause(s) from the list of identified root causes.

Highlight, box, or circle the identified root cause(s) so they stand out on the Cause & Effect Diagram.

ABC Team
Selects the Root Cause(s)

The team used a marker to highlight the possible root cause(s).



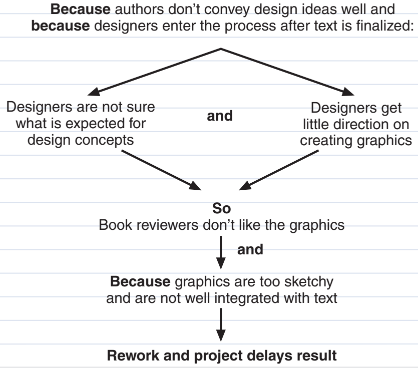
ABC Team
Selects the Root Cause(s), continued

Now the team looked for ways to logically describe how one or more ideas could be the root cause(s). Felicia noticed that "too sketchy," "little direction on creating graphics," and "authors don't convey design ideas well" were related to book reviewers not liking the graphics. Everyone else agreed.

Stephano pointed out that before the company merger, designers had worked closely with authors but now worked separately. He speculated that many of the graphics needed rework because the authors didn't explain to the designers what information the graphics were meant to convey.

Jeremy suggested that they use a diagram to show other managers how the team traced the root cause to the problem.

Logic Diagram



Because authors don't convey design ideas well and
because designers enter the process after text is finalized:

Designers are not sure what is expected for design concepts

and

Designers get little direction on creating graphics

So
Book reviewers don't like the graphics

and

Because graphics are too sketchy and are not well integrated with text

Rework and project delays result

5. **Verify the root cause(s).**
    - If possible and practical, conduct a test under controlled conditions (Design of Experiments) to determine the effects of changes to the suspected root cause(s), or to cause the problem to appear in otherwise stable processes.

How can I turbo-charge this step?

Weighted Criteria Decision Matrix

There will be some situations where teams don't have enough data to help them reach a conclusion on the root cause(s) of the problem. In these situations, teams can use a Decision Matrix to reach consensus on the most likely root cause(s). This tool helps a team compare the leading candidates for the root cause against criteria that the team decides are important for selecting a root cause. Use the following steps to construct a Decision Matrix.

1. Weight each criterion on a scale of 1–9, with "1" indicating a low value and "9" indicating a high value. Make sure each criterion has a different weight.
    - Your team's criteria may change depending on the problem. Some examples of criteria include:
        - Creates exciting quality for the customer.
        - Can be implemented quickly.
        - Creates a positive change.
        - Cost is minimal or within budget.
        - Minimal resistance to changing the root cause.

2. Rate each possible root cause against each criterion. An example of a rating system the team may use:

   9 = Strongly meets the criterion

   5 = Moderately meets the criterion

   1 = Weakly meets the criterion

   Place the team's ratings in the top-left portion of each "cell" in the matrix.
3. Multiply each rating by the weight of the criterion and place this number in the bottom-right portion of each cell.
4. Tally the scores and select the root cause with the highest score.

Weighted Criteria Decision Matrix

Notice that root cause #1 has the highest score. The team would address this root cause.

Criteria	Weight	Root Causes		
		1	2	3
1. Creates exciting quality for the customer	9	9 81	5 45	5 45
2. Can be implemented quickly	7	9 63	5 35	1 7
3. Creates a positive change	5	1 5	0 0	5 25
	Totals	**149**	80	77

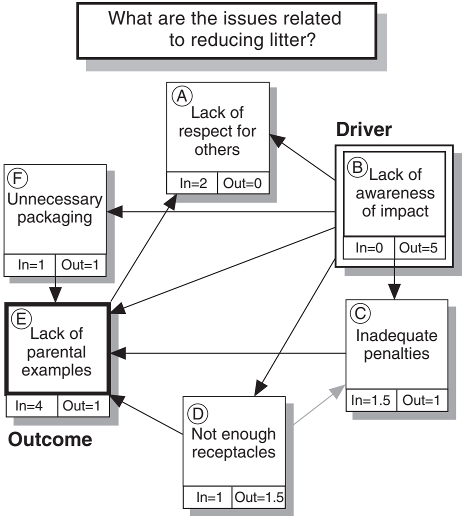
Interrelationship Digraph (*MJII*, p. 76.)

The Interrelationship Digraph (ID) is an excellent tool to use when there is a high degree of uncertainty in the problem and there is little or no historical data available to guide the team. The ID, which shows the cause and effect relationships among possible causes of an outcome, allows a team to identify the key drivers of a desired outcome.

Use the following steps to construct an ID.

1. Agree on the desired goal, objective, or outcome and phrase it as a question.
2. Use separate Post-it™ Notes or cards to list the team's ideas on what could cause or influence the outcome. Use large, bold printing, including a large number or letter on each idea for quick reference. Keep the number of ideas manageable, between 5 and 25.
3. Arrange the cards or notes in a large circle. Leave enough space so that the team can draw lines between the ideas.
4. Look for cause/influence relationships between all of the ideas and draw relationship arrows.
    - Choose any of the ideas as a starting point. When a relationship exists between two ideas, draw a relationship arrow from the one that causes or influences the other.
5. Tally the number of outgoing and incoming arrows for each idea. Write the tally for outgoing and incoming arrows next to each idea.
    - Find the idea with the highest number of outgoing arrows and label it as the "Driver."
    - Find the idea with the highest number of incoming arrows and label it as the "Outcome."

Interrelationship Digraph

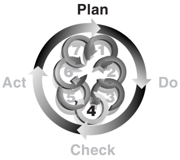


Reproduced from the MJII, p. 80.

Step 4

Develop a Solution and Action Plan:

Develop an effective solution and action plan, including targets for improvement.



What does this step do?

Helps teams develop practical solutions and an action plan to effectively address the root cause(s) of a problem, and produce a desired effect or outcome.

What concepts must I understand to do this step?

Finding New Approaches Can Require Innovative Thinking

People interpret information and situations based on past experience. This helps them to build on existing knowledge of what works. However, these experiences can also trap people into automatically using methods that worked in the past when the current situation requires innovative thinking. To prevent this from happening, teams can ask:

- Has the situation happened before?
- What did the team and/or organization do?
- What were the results?
- How is it different this time?
- What could be done differently to get better results?
- What are alternative ways of solving the problem?

Benefits of an Action Plan

The plan should describe expected results, tasks that need to be accomplished, start and end times for tasks, names of individuals who are responsible for completing assigned tasks, an assessment of the risks, and estimates of costs and staff resources. The benefits of an action plan are:

- Good communications within the team and among stakeholders.
- Focused energy.
- The team has a baseline for measuring effectiveness.
- People know what is expected of them and can perform better with this knowledge.
- Teams have a method for evaluating alternatives against important criteria, sequencing tasks, and estimating resources (such as time, costs, and staffing needs.)

Importance of Assessing Risks and Building Countermeasures into the Plan

When teams implement a new process or make a major modification to a process, there is always a degree of risk. One way to reduce the risk is to identify areas where something could go wrong during implementation (a contingency), and then plan countermeasures to put in place if the contingency becomes real.

What actions must be taken in this step?

- **Generate** potential **solutions**.
- **Select** the most effective **solution**.
- **Generate all possible tasks** that can be done to implement the solution.

- Anticipate likely problems (contingencies) and **develop possible countermeasures**.
- **Create** an **action plan**.

How do I do it?

1. **Generate potential solutions.**
    - In preparation for this step, make sure that your team includes the people who are most familiar with the problem or process, as well as customers of the process.
    - Write down the root cause(s) of the problem so that the team can refer to it (them) while composing the solution statement(s).

    a) Write one or more solution statements for each root cause.

    - There are three components of an effective solution statement: 1) the action the implementation team will take; 2) what or whom the action will involve; and 3) what the desired effect will be.

What action will you take?	+	To what? Or with whom?	+	To produce what desired effect?
Replace	+	spark plugs	+	to increase fuel economy
Improve training	+	for all employees	+	to reduce turnover
Provide recommended maintenance	+	on photocopiers	+	to reduce paper waste caused by jams

b) Other methods for generating potential solutions are Classic Brainstorming (*MJII*, p. 19 or *CTMJ*, p. 31) and Imaginary Brainstorming (*CTMJ*, p. 39).

- If the results from Classic Brainstorming are inadequate, try using Imaginary Brainstorming to stretch each team member's thinking.
- If the team has a list of ideas that were generated by Classic Brainstorming, hold onto it. Classic Brainstorming is the first step in the Imaginary Brainstorming process.

ABC Team Composes a Solution Statement

When team members reviewed the Cause & Effect Diagram, they all agreed that the delays in product development were caused by the graphic designers and authors not consulting with one another. Consequently, the graphics were unacceptable and had to be reworked most of the time. The team composed the following solution statement:

What action will you take?	+	To what? Or with whom?	+	To produce what desired effect?
Change	+	the authoring and graphics production phases	+	to reduce graphics rework and to complete projects as scheduled

2. **Rank potential solutions; select the best solution.**

   a) Identify the selection criteria that will be used to rank the solutions.

   - Identify the most important customer needs. These needs should always be the team's first consideration for defining criteria for selecting a solution. Any solution that fails the "customer test" should not go any further in the problem-solving process.
   - Agree on the additional criteria that will be used by the team to assess all of the potential solutions. Typical criteria include:
     - Level of complexity
     - Level of resources required
     - Amount of time required for implementation
     - Degree of control by the team
     - Probability of change
     - Impact on the problem (high, medium, low)

> Limit the number of criteria to a maximum of three or four. Evaluating the solutions against too many criteria can become a complex and tiresome process.

   b) Use a Matrix Diagram (*MJII*, p. 85), Weighted Criteria Decision Matrix (p. 58 in this book), or the Prioritization Matrices tool (*MJII*, p. 105) to select the best solution.

   - Plot the solutions against the criteria.
   - Unless there are significant disagreements among team members, the criteria can be used as if they are all equally important.

Matrix Diagram Example

Criteria Solutions	Criterion 1	Criterion 2	Criterion 3
Solution 1	High	Medium	Low
Solution 2	High	High	High
Solution 3	Low	High	Medium
Solution 4	Low	Medium	Medium

High = Strongly meets criterion
Medium = Moderately meets criterion
Low = Weakly meets criterion

When ranking the solutions, limit the number of solutions to no more than eight. If the team has more than eight, narrow down the list by consensus or a ranking method such as Multivoting or Nominal Group Technique (*MJII*, p. 91).

- If the criteria are not equally important, use a Weighted Criteria Matrix or the Prioritization Matrices tool (*MJII*, p. 105).
- When teams use the Full Analytical Criteria Method for the Prioritization Matrices tool, it forces a discussion of assumptions right from the beginning of the comparison of criteria. Each step of the process gives team members a chance to understand why people may agree or disagree over the relative importance of the criteria.

- Remember that team members often rank several different solutions very highly. The team should feel free to choose one from the top two or three highest ranked solutions without agonizing over the math. In fact, sometimes for the best results, the team should pursue more than one solution at a time.

The following example is a simple illustration of the Full Analytical Criteria Method for constructing the Prioritization Matrices. (For more detailed examples, see the Coach's Guide to The Memory Jogger™ II, *pp. 150–153 or* The Memory Jogger Plus+®, *pp. 99–134.)*

Prioritization Matrices Example: Improving the Lead Time for Restocking Books in Inventory

Criterion vs. Criterion Matrix

Weighting the Criteria

Criteria	Cost to implement	Quick to implement	Acceptable by employees	Level of training needed	Impact on other departments	Row Total (5 criteria)	Relative Decimal Value (Divide Row Total by Grand Total)
Cost to implement		1/10	1/5	1/5	1/10	.60	.01
Quick to implement	10		5	1	5	21	.36
Acceptable by employees	5	1/5		1/5	1/5	5.6	.10
Level of training needed	5	1	5		5	16	.27
Impact on other departments	10	1/5	5	1/5		15.4	.26
					Grand Total (5 criteria)	58.6	

Weighted Scale

1	= Equally important
5	= More important
10	= Much more important
1/5	= Less important
1/10	= Much less important

For each weight (e.g., 1, 5, 10) recorded in a row cell, also record its reciprocal value (e.g., 1/5, 1/10) in the corresponding column cell.

Before adding together the scores, convert the 1/5 and 1/10 fractions to decimal values, e.g., 1/5 = .20 and 1/10 = .10.

Solutions vs. Each Criterion Matrix

(Cost Criterion)

Cost to implement	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Row Total	Relative Decimal Value (Divide Row Total by Grand Total)
Solution 1		5	1/10	1/10	1/5	5.4	.09
Solution 2	1/5		5	10	5	20.2	.32
Solution 3	10	1/5		1	5	16.2	.26
Solution 4	10	1/10	1		1/5	11.3	.18
Solution 5	5	1/5	1/5	5		10.2	.16

Grand Total 63.3

Weighted Scale

1 = Equal cost
5 = Less expensive
10 = Much less expensive
1/5 = More expensive
1/10 = Much more expensive

- For each criterion, create an L-shaped matrix with all of the solutions on both the vertical and horizontal axis and the criteria listed in the left-hand corner of the matrix. *There will be as many solutions matrices as there are criteria to be applied.*

Prioritization Matrices Example, continued

Solutions vs. Each Criterion Matrix

(Quick to Implement Criterion)

Quick to implement	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Row Total	Relative Decimal Value (Divide Row Total by Grand Total)
Solution 1		10	5	5	5	25	.45
Solution 2	1/10		1	5	10	16.1	.29
Solution 3	1/5	1		5	5	11.2	.20
Solution 4	1/5	1/5	1/5		1	1.6	.03
Solution 5	1/5	1/10	1/5	1		1.5	.03
					Grand Total	55.4	

Weighted Scale

1 = Equal amount of time to implement
5 = Less time to implement
10 = Much less time to implement
1/5 = More time to implement
1/10 = Much more time to implement

Use the same scale you used for comparing each criterion against one another, 1, 5, 10, etc., but customize the wording for each criterion. Note that 5 and 10 weights are always used for the positive or desirable condition, and the reciprocals 1/5 and 1/10 used for the negative or undesirable condition. For example: with the criterion "cost to implement," it is usually desirable if implementation is "*less* expensive," (a weight of 5). With the criterion "acceptable by employees," it is usually desirable to implement a solution that is "*more* acceptable by employees," (also a weight of 5).

Solutions vs. Each Criterion Matrix

(Acceptable by Employees Criterion)

Acceptable by employees	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Row Total	Relative Decimal Value (Divide Row Total by Grand Total)
Solution 1	■	1/5	1/5	1/10	1/10	.60	0
Solution 2	5	■	1/5	1/5	1/10	5.3	.08
Solution 3	5	5	■	1/5	1/5	10.2	.15
Solution 4	10	5	5	■	1/5	20.2	.30
Solution 5	10	10	5	5	■	30	.45
					Grand Total	66.3	

Weighted Scale

1 = Equally acceptable
5 = Less acceptable
10 = Much less acceptable
1/5 = More acceptable
1/10 = Much more acceptable

Solutions vs. Each Criterion Matrix

(Level of Training Needed Criterion)

Level of training needed	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Row Total	Relative Decimal Value (Divide Row Total by Grand Total)
Solution 1	■	1	5	1/5	5	11.2	.20
Solution 2	1	■	5	1	10	17	.31
Solution 3	1/5	1/5	■	1/10	5	5.5	.10
Solution 4	5	1	10	■	5	21	.38
Solution 5	1/5	1/10	1/5	1/5	■	.70	.01
					Grand Total	55.4	

Weighted Scale

1 = Equal training needed
5 = Less training needed
10 = Much less training needed
1/5 = More training needed
1/10 = Much more training needed

Prioritization Matrices Example, continued

Solutions vs. Each Criterion Matrix

(Impact on Other Departments Criterion)

Impact on other departments	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Row Total	Relative Decimal Value (Divide Row Total by Grand Total)
Solution 1		5	5	1	10	21	.37
Solution 2	1/5		1	5	10	16.2	.28
Solution 3	1/5	1		5	10	16.2	.28
Solution 4	1	1/5	1/5		1	2.2	.04
Solution 5	1/10	1/10	1/10	1		1.3	.02
					Grand Total	56.9	

Weighted Scale

1 = Equal impact
5 = Less impact
10 = Much less impact
1/5 = More impact
1/10 = Much more impact

- Use the weighted criteria matrix (see p. 68) to transfer the relative decimal values to each criterion in the summary matrix.
- Using one "solutions vs. each criterion" matrix at a time (pp. 69–72), transfer the relative decimal values for each solution to the corresponding criterion column in the summary matrix.
- Multiply the two numbers in each cell to get a score for each cell in the row; add the scores to get a row total for each solution; and lastly, figure out the relative decimal values for each solution.

Summary Matrix

Solutions vs. All Criteria

Criteria Solutions	Cost to implement (.01)	Quick to implement (.36)	Acceptable by employees (.10)	Level of training needed (.27)	Impact on other departments (.26)	Row Total	Relative Decimal Value (Divide Row Total by Grand Total)
Solution 1	.01 x .09 = 0	.36 x .45 = .16	.10 x 0 = 0	.27 x .20 = .05	.26 x .37 = .14	.35	.35
Solution 2	.01 x .32 = 0	.36 x .29 = .10	.10 x .08 = .01	.27 x .31 = .08	.26 x .28 = .07	.26	.26
Solution 3	.01 x .26 = 0	.36 x .20 = .07	.10 x .15 = .02	.27 x .10 = .03	.26 x .28 = .07	.19	.19
Solution 4	.01 x .18 = 0	.01 x .03 = .06	.10 x .30 = .03	.27 x .38 = .03	.26 x .04 = .01	.13	.13
Solution 5	.01 x .16 = 0	.36 x .03 = .10	.10 x .45 = .05	.27 x .01 = 0	.26 x .02 = .01	.07	.07
					Grand Total	1.00	

- Compare the final decimal values to help you decide which solutions are the best ones to pursue.

3. Generate all possible tasks that can be done to implement the solution.

- Use the solution statement to think about and brainstorm potential possible ways to implement the solution. (See Brainstorming in *MJII*, p. 19 or *CTMJ*, p. 31.)

ABC Team Brainstorms Tasks

The team used Classic Brainstorming to generate a list of possible tasks to reduce graphics rework.

Change standard procedures

Compare old and current process

Ask designers to review marketing research

How do other publishers run projects?

How do other industries use creative teams?

Include designers in focus groups

Change the process

Have designers & authors create design ideas

Add graphics staff to the team

Provide team building training

Decide who has final say

Create different process scenarios

Give designers & authors personality tests and match them

Study practices of award-winning publishers

Benchmark other industries

4. **Construct a detailed action plan.**

   - A solution is only as effective as its action plan. A good plan will document the identified tasks to implement the solution, the necessary resources, the required tasks, and the names of individuals or groups who are assigned the responsibility for completing the tasks.
   - The plan will also include milestones for assessing progress toward the team's goals or targets, as well as measures on the performance of the process. Use the table on the next page as a reference for understanding the basic elements of a good plan. (For more detailed information on developing the elements of a good plan, consult the *PMMJ*, pp. 51–134.)
   - The following sections a) through e) are a suggested tool set for teams to develop a detailed action plan.

   a) Use an Affinity Diagram to organize the team's list of potential tasks into broad groupings of tasks. (*MJII*, p. 12 for Affinity Diagram and *MJII*, p. 158 for Action Affinity.)

   - Without talking ("silent sorting"), sort the brainstormed list of cards or Post-it™ Notes into groupings that express similar themes.
   - Create summary or header cards for each grouping. The team should agree on a concise statement that best describes the grouping's central idea.

Elements of a Good Action Plan*

Element	Purpose
Define the scope (implementation of the solution)	To produce a plan that will satisfy everyone's needs. It will define the customers and what results they expect, and defines the criteria for judging the satisfaction with the results.
Complete the list of required reviews and approvals	To define the reviews and approvals that allow the team to keep on track and moving forward with everyone's approval.
Assess the risks	To understand the obstacles that could prevent the implementation of the plan.
Complete the list of required status reports	To define the reports that will be distributed to the team members, team sponsor, and customers on the progress of the project. It will highlight any problems that are occurring and what's being done to overcome them.
Review the team membership	To ensure that the team members continue to bring the right skills and expertise to the problem-solving effort. If additional skills and knowledge are required, the team will need to find and include these people on the team.
Create a schedule	To coordinate the activities efficiently to meet the deadline.
Estimate the staff effort required	To estimate the time required to make the needed resources available, and to identify activities that may interfere with other work assignments.
Create a budget	To identify costs that will be incurred to carry out the action plan.
Assemble the plan	To document the plan for final review and approval by the team, sponsor, and customers.

**The information in this table was adapted from the* PMMJ, *Chapter 4, "How to Create a Project Plan," pp. 51–134.*

b) Use a **Tree Diagram** to map out detailed levels of tasks. (*MJII*, p. 156.)

- Use the header cards from the team's Affinity Diagram for the major headings in a Tree Diagram. These task areas are the major "sub-goals" or "means" by which the plan will be achieved.
- Break down each major task area into more detail by providing answers to the question: "What needs to be addressed to achieve the solution?" (Keep the tasks at roughly the same level of detail.) Repeat the question for each successive level until the team agrees there is enough detail to complete the plan or until the assignable tasks can be delegated.
- Review the completed Tree Diagram to determine if all the tasks need to be done. If team members are unsure about the value of some tasks, use a Decision Matrix or the Prioritization Matrices tool to evaluate the possible tasks against important criteria, such as costs, risks, timelines of completion, ease of implementation, and feasibility.
- Review the completed Tree Diagram to determine if all the necessary tasks are included. If necessary tasks were omitted, add them to the diagram.

✓ As each level of detail is developed, the team should ask, "Is there anything that we've forgotten?" before moving on to the next level.

✓ Some items may need additional levels of detail to be complete.

c) Use a **Responsibility Matrix** (*MJII*, p. 85 for Matrix Diagram) to show which individuals are responsible for carrying out the key tasks in the Tree Diagram and include the time, budget, and staff allocations for each task. The team needs to address these questions:

- Who is responsible for seeing that the task is completed?
- When will the task begin?
- When will the task end?
- What is the budget for completing the task?
- What staff resources will be allocated to complete the task? (Staff days, weeks, months?)

d) Prepare a **Gantt Chart** to use as a scheduling and monitoring tool. (*MJII*, p. 9.)

- On the vertical axis, list all the tasks that must be completed.
- Across the top of the horizontal axis, list the time periods covered in the project plan. These could be days, weeks, months, quarters, years, etc.
- Indicate the starting and ending date for each task with a horizontal bar. (This information may already be available if the team has created a Responsibility Matrix.)
- Include a list of key dates below the Gantt Chart to highlight the milestones of the project.

e) Use the **Process Decision Program Chart (PDPC)** to develop countermeasures for problems that may occur during the implementation of the plan. (*MJII*, p. 160.)

- The PDPC is an ideal tool to help teams anticipate potential problems before they occur.
- Determine proposed implementation steps. These steps can be taken from the Tree Diagram.
- Develop a list of potential and likely problems (contingencies) that could interfere with the successful completion of a step by asking "What could go wrong?"
- Branch likely problems off each step.
- Branch possible and reasonable countermeasures off each likely problem.
- Choose the most effective countermeasures and build them into the plan.

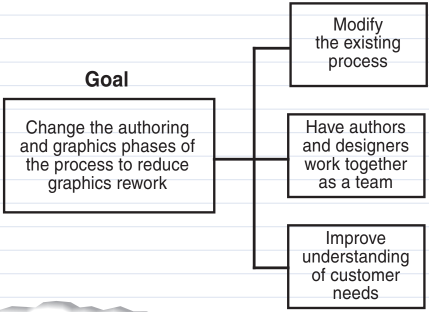
ABC Team Groups Potential Tasks Using the Affinity Diagrams

Goal: "Change the authoring and graphics production phases of the process to reduce graphics rework and complete projects as scheduled."

Modify the existing process	Have authors and designers work together as a team	Improve understanding of customer needs
Compare old and current process	How do other publishers run projects?	Ask designers to review marketing research
Change standard procedures	How do other industries use creative teams?	Include designers in focus groups
Change the process	Provide team building training	Add graphics staff to the team
Create different process scenarios	Decide who has final say	Have designers & authors create design ideas
Study practices of award-winning publishers	Give designers & authors personality tests and match them	
Benchmark other industries		

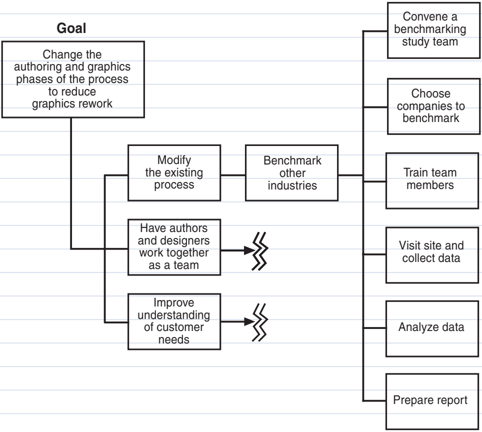
ABC Team Maps Out Tasks with Tree Diagram

The team used the header cards from the Affinity Diagram to create the first level of the Tree Diagram.



ABC Team's Tree Diagram, continued

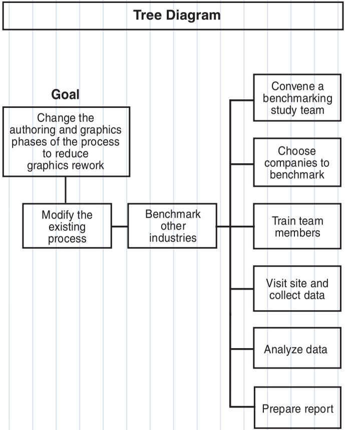
The team then filled in additional levels of detail by asking: "What needs to be addressed to achieve the solution?" for each successive level. Part of the team's diagram is shown below.



ABC Team Creates Responsibility Matrix

After completing the Tree Diagram, the team developed a Responsibility Matrix.

Tree Diagram

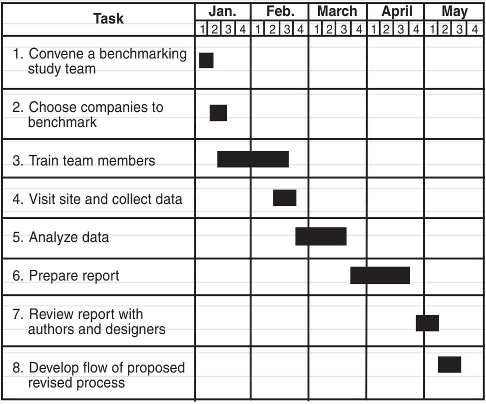


Responsibility Matrix

Assigned To	Start Date	End Date	Budget	Staff Days
Jeremy, Team Leader	Jan. 6	Jan. 9	0	3
Raphael, Director of Operations	Jan. 12	Jan. 16	0	5
Delaney, Director of Human Resources	Jan. 12	Feb. 10	$2,500	21
Raphael, Director of Operations	Feb. 12	Feb. 23	$4,000	10
Jeremy, Team Leader	Feb. 24	March 19	$400	21
Jeremy, Team Leader	March 21	April 19	$250	24
		Totals	$7,150	84 days

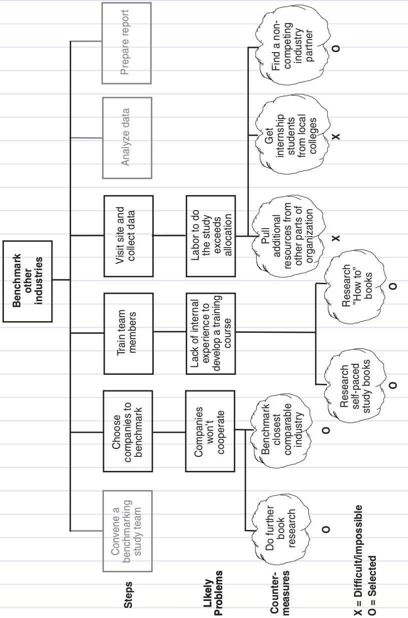
ABC Team Creates Gantt Chart

The Gantt Chart below shows the timelines for the various activities that were planned to solve the rework problem. Jeremy, the team leader, used this chart and the Responsibility Matrix (on previous page) to prepare for a briefing with other managers.



ABC Team Creates PDPC

Because ABC had never done a benchmarking study (Task 2 in the Gantt Chart), team members agreed that this was an area where they were unsure if the planned budget and time allocations were correct. The team used a PDPC to look at what factors might interfere with the successful completion of this task and selected several countermeasures to use if the problems actually occurred.



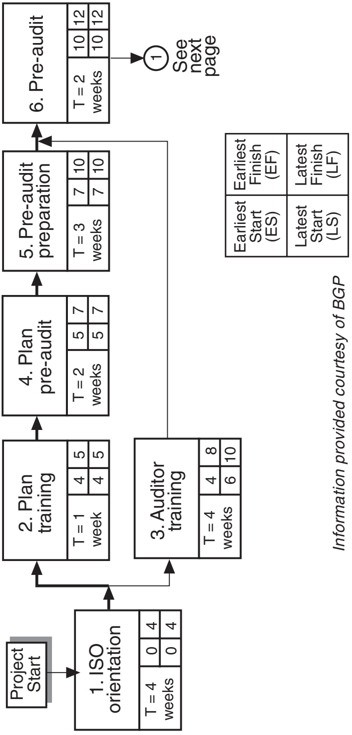
How can I turbo-charge this step?

The Activity Network Diagram (*MJII*, p. 3).

This tool allows a team to find the most efficient path and realistic schedule for the completion of a project by graphically showing total completion time, the necessary sequence of tasks, those tasks that can be done simultaneously, and the critical tasks to monitor.

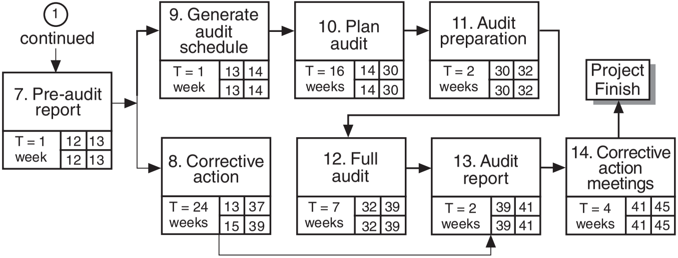
1. Record all of the tasks that need to be accomplished on separate cards or Post-it™ Notes.
2. Find the first task that must be done and place it on the extreme left of a large work surface.
3. Place other tasks that can be done simultaneously above or below the first task.
4. Ask, “What is the next task that must be done?” “Can others be done simultaneously?”
5. Repeat this questioning process until all the recorded tasks are placed in sequence left to right on the page. Use parallel paths whenever possible.
6. Number each task, draw the connecting arrows, and write in the time needed to complete each task.
7. Determine the project’s critical path. (Teams can either calculate the longest cumulative path or identify the tasks with no “slack” time.)
8. Determine the total time to complete the project.

Phase 1: ISO 9000 Certification Audit Schedule



Information provided courtesy of BGP

Activity Network Example, continued



Information provided courtesy of BGP

Note: The AND shows that the certification process will take 45 weeks. The bold arrow, indicating the critical path, clearly shows those tasks that must be completed as scheduled. The tasks off the critical path will also require careful monitoring since there is only two weeks of slack time in the schedule.

Example reproduced from
The Memory Jogger™ II, *pages 10 and 11.*

Morphological Box *(CTMJ, p. 71).*

Teams may want to consider different solution scenarios to find the one that best fits their needs. The Morphological Box helps a team build these scenarios by creatively linking different options for the key parameters of the solution.

1. List the selected parameters in the left-hand column of the table.
    - A parameter is a characteristic that a solution must have to be effective.
2. Generate practical options for each parameter. Identify a minimum of two, but usually no more than five or six. More options are not always better.
    - Options are different ways that a parameter can be met.
3. Build alternative solution scenarios by linking different options.
    - Use a different symbol for each scenario. Suggestions: square, circle, oval, triangle.
    - Draw the symbols in the selected option "cells," then link similar symbols by drawing a line between them.
4. Summarize the alternative solution scenarios in narrative form.
5. Select the best solution(s).

Designing a New Process for Selecting Managers at Compass Products

Parameters	Options				
Participants	Peers ●	Reports	Bosses	Internal customers ☆	Supplier
Atmosphere	Formal ☆	Informal ●			
Areas of Inquiry	Technical knowledge ☆	Values ●	Decision-making style	Communications style	Teamwork style
Decision-Making Method for Selecting the Person	Consensus ☆	Unanimity ●	Majority rules	Boss's choice	
Number of People Interacting	One on one ●	Team ☆			
Process Documentation	Notes ●	Video ☆	Audio		
Location of the Process	Facility ☆ ●	Corporate offices	Assessment center		

Alternative #1 ☆ Alternative #2 ●

Continued on next page

Morphological Box Example, continued

Analysis

The Morphological Box made it possible (theoretically) for the team to consider as many as 3600 unique models for selecting a new manager. Out of the handful that it reviewed closely, the team chose two alternatives.

In the first alternative, (the gray stars), **a team** of **internal customers** would assess each candidate's **technical knowledge** by working with him/her in a **formal atmosphere** to solve a real operational problem at the **facility**. After the team reviews the **videotape** of the sessions, a candidate would be recommended based on the **consensus** of the team.

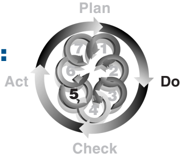
The second alternative, (the blue circles), would include all of the candidate's **peers** holding **informal, one-on-one meetings** with the candidates at the **facility** in order to assess each candidate's fit with the core **values** of the organization. Based on each person's **notes**, the chosen candidate must be recommended **unanimously**.

Example reproduced from
The Creativity Tools Memory Jogger™ II*, pages 81 and 82.*

Step 5

Implement the Solution:

Implement the solution
or process change.



What does this step do?

Helps teams to follow their action plan to solve a problem or improve a process.

What concepts must I understand to do this step?

Leadership Responsibility

- It is the team's responsibility to "sell" the benefits of the action plan to managers, associates, and others who are affected by the problem and the project.
- The team should widely communicate the action plan through briefings, newsletters, posters, and other displays. This keeps the plan highly visible, and keeps others in the organization informed about the team's progress and interim accomplishments.
- Leaders have a responsibility to ensure that people have the resources they need to implement the action plan.

Accountability

- The team is accountable for completing the tasks in the action plan. To do this, the team should make one person accountable for completing each task in the plan.

- It is the team's job to monitor and document the progress of the plan and any discrepancies that occur during the implementation of the plan. (These discrepancies are called "variances.")
- It's important that the team schedule briefings with management to report on progress, roadblocks, and modifications to the plan.
- As each plan objective is met, inform all the team members and others in the organization who need to know.

Motivation and Morale

- Leaders need to remove any barriers that may impede the progress of implementing the plan.
- Leaders need to help team members stay focused and motivated, and feel supported and rewarded as they "work the plan." This is especially important during the early stages of implementation, where misunderstandings and conflicts among team members are likely to occur.
- Team members should remember to give each other support and understanding during stressful times of the implementation.

What actions must be taken in this step?

- **Practice good communication** skills**.**
- **Develop** good team **meeting skills.**
- **Analyze data** to determine what changes are needed, if any, and to **document** the team's **ongoing assessment of the plan**.
- **Make effective and timely decisions** based on data, not hunches, whenever possible.

How do I do it?

1. Communicate the plan.

- Get the plan approved.
- All team members should understand their roles and responsibilities in carrying out the planned activities and should know the details of the plan, including milestones and what reports will be required.
- Explain the plan to people who will be affected by the plan's activities. This will help people understand the full scope of the plan, see when and how they will be affected by the plan, and to "buy in" to the benefits of the plan. Consider addressing these questions:
    1. What activities are planned?
    2. What will the implementation cost?
    3. What staff resources are needed?
    4. When will the implementation of the plan be completed?
    5. What are the benefits of carrying out the plan?

ABC Team Discusses the Plan

After the team developed an action plan (Step 4), the team scheduled a meeting and briefed Hanna Gibbons, the project sponsor, on the following information:

- The tasks/activities in the plan.
- The budget to implement the plan.
- Staff requirements.
- Projected beginning and ending dates for implementing the plan.
- The benefits of the plan.

During the briefing, Hanna suggested a less expensive and less time-consuming way of conducting the benchmarking study, and indicated that she wanted a weekly briefing on the team's progress.

2. **Carry out and monitor the implementation.**
   - Carry out the action steps to achieve interim and final objectives of the plan.
   - Monitor the time spent on the project and the resources used to ensure that the schedule, budget, and resources stay within the limits established in the plan.
   - Measure the performance of the implemented solution against the plan.
     - Name one person to be responsible for recording and reporting the actual performance of the solution against the plan.
     - Modify the plan and get approval, as needed.

- Implement any countermeasures when anticipated obstacles actually occur. See page 77 for a description of how the Process Decision Program Chart is used in planning countermeasures.
- Document the changes.

ABC Team Implements the Plan

As the benchmarking team members began the detailed planning for their site visit, they soon recognized that the resources assigned would be inadequate to complete the tasks during the allotted timeframe.

Extending the timeframe would delay the data analysis to such an extent that the completion schedule would be delayed.

The team recommended implementing the planned countermeasure for this problem, i.e., “find a non-competing industry partner.” Since the industry partner had already been identified and contacted, the team scheduled a meeting to identify roles and finalize the details of the joint site effort.

ABC Team
Implements the Plan, continued

Task	Assigned To	Start Date	Planned End Date	Actual End Date	Corrective Action(s) Taken
Convene a benchmarking study group	Jeremy, Team Leader	Jan. 6	Jan. 9	Jan. 9	None
Choose companies to benchmark	Raphael, Director of Operations	Jan. 12	Jan. 16	Jan. 16	None
Train team members	Delaney, Director of Human Resources	Jan. 12	Feb. 10	Mar. 1	None
Visit site and collect data	Raphael, Director of Operations	Feb. 12	Feb. 23	Mar. 5*	Contacted non-competing business partner to participate in the site visit.

*Explanation: The ABC team's resources are not adequate to complete the site visit and to collect benchmarking data within the time allotted.

ABC Team Implements the Plan, continued

The team also scheduled lunch hour briefings to keep other employees informed about the progress of the implementation.

The team used the results of the benchmarking study to conclude they needed to create a space just for designers and authors to meet and discuss design concepts.

In the revised process, authors and designers used the "design concept room" to create three different designs for book graphics. These designs were included with the book draft sent to the book reviewers.

3. Meet regularly to share information on the implementation.

- Have regularly scheduled review meetings to inform managers and others about progress, delays, and needed adjustments.
  - Create agendas for meetings.
  - Develop and maintain effective team meeting skills, which include listening, giving and receiving feedback, adhering to the team's ground rules, and learning how to handle conflicts between team members.
- Issue status reports.
  - Determine who should receive them.
  - Create a checklist of what information should be included in each report.

  - Report on discrepancies (variances) and the team's corrective actions, if any.

- Keep everyone informed about the implementation of the plan by using a well publicized and highly visible storyboard or write regular updates for the company newsletter or Intranet site. (See Chapter 4, p. 121 to learn more about storyboards.)

The team's documentation of variances from the plan and/or implemented corrective actions/countermeasures can provide valuable input for the team's later review of "things that helped" and "things to avoid" in the future.

ABC Team Reports on Progress of the Plan

Team members met regularly to discuss progress on the implementation. To keep others in the organization informed on the implementation, the team:

- Wrote an article for the company newsletter explaining the goals of the improvement plan and the key events and dates.
- Updated the storyboard to track the progress of the implementation plan.
- Conducted a briefing to explain the revised process and "design concept room" to other employees.

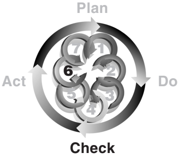
How can I turbo-charge this step?

Use project-planning software to track the performance of the implemented solution against the plan. This will enable the team to see if the project is running ahead of or behind schedule, and if it is on target with the allotted resources, i.e., money and labor. Many of the graphic capabilities of the software can also be used for briefings and to update the team's storyboard.

Step 6

Review and Evaluate:

Review and evaluate
the results of the change.



What does this step do?

Helps teams assess the results of the change and evaluate whether the change met the team's objectives.

What concepts must I understand to do this step?

The Power of the Plan-Do-Check-Act (PDCA) Model

When teams use a systematic approach to problem solving, problems are solved more efficiently, teams' efforts are focused and directed, and the results gain greater credibility with management and with their customers.

The Power of the Standardize-Do-Check-Act (SDCA) Model

When the changes that teams make are the right ones, teams should *standardize* them. This sub-cycle of the PDCA model ensures that process improvements are made permanent.

Learn from Experience

When teams take the time to review and evaluate the processes they used to solve a problem, the organization can learn from the teams' experiences. This review can help others to be more efficient and effective in the future.

What actions must be taken in this step?

- **Understand** the importance and role of process and outcome **measures**.
- Know how to **interpret** a **Run Chart** and **Pareto Chart**.
- **Create** and maintain **procedures, documents, and records**.
- **Communicate** process **changes.**

How do I do it?

1. Review the results of the change.

- Is there a difference between present and past performance?
- What are the team's success measures? Did the team meet its targets? If yes, continue to implement the plan. If no, find out why.
- Did the solution work? If not, try any of the following:
  - Examine the team's thinking process that led to the chosen solution.
  - Use a Check Sheet, Pareto Chart, Run Chart, Control Chart, or Histogram to check the results of the change and to compare prior performance with current performance. (To determine which one of these tools is most appropriate, consult the table on page 54.)
  - If new issues have surfaced as a result of the change made, use the Affinity Diagram to categorize them. (*MJII*, p. 12.)
  - To confirm whether the team's solution to the problem was the best choice, create a new Pareto Chart that relates to the new Flowchart of the process. Look for a relationship between

    the changes made in the sub-step measures and the overall process measures to confirm the solution.

  - Review, refine, or redo the Cause and Effect Diagram to see if the team can identify another root cause.

  - Develop an alternative solution.

- Modify the process to prevent a recurrence.

Whatever tools were used in Step 3 to validate the root cause, before the change was made, should also be used after the change is made.

Changes made to increase the speed of a process may not produce the desired results until all people working in the process are familiar with the new steps.

ABC Team Discusses How to Evaluate the Results

After using the revised process for the next book project, the team compared these results against the data for previous projects to determine if the change was an improvement.

To evaluate the results, the team wanted to know:

- Is the process substantially changed? Do managers and associates perceive the change as an improvement?
- Is there a reduction in the number of graphics that needed to be reworked after the second book review? What is the extent of the reduction?
- Are projects completed on time?
- Do authors and graphic designers work well as a team?
- Is employee morale improving?
- Are there any unanticipated benefits or negative consequences?

With the newest book project, only six of the 45 graphics needed rework after the second book review and the project was completed two days ahead of schedule. This was a substantial improvement!

2. Revise the process as necessary.

- Use the information the team has gathered so far to fine-tune the process.
- Brainstorm countermeasures for problems as they surface. Then revise the team's process Flowchart as necessary. Keep revising the process until the team is satisfied that the problem has been solved.
- The team may decide to establish new measures for monitoring the process.

When the process is working well, the team might consider reducing the frequency of measures. This can lead to cost savings.

3. Standardize the improvement.

a) Get the change approved. The steps necessary to standardize a change depend on the requirements of your organization.

- Many organizations require formal approval from management, customers, or regulators (or all three) before an improvement can become a part of the standard process.
- The time a team invests to confirm and document the root cause of the problem will give the team's efforts important credibility and speed the standardization of the solution.

b) Communicate the following information to all the people affected by the change:

- The process (and its name)
- The problem
- The root cause(s) of the problem
- The solution(s) to the problem

  - What each person must do differently (and the same) to remove the root cause(s)
  - Written instructions, directives, and memos about the change
  - The new measures that have been put into place to monitor the process
- It is important to communicate the changes to the right people. Include suppliers and customers, as well as other people who work in the process. Also, don't forget about communicating improvements to other functional areas.
- Identify the ways that information is shared in your organization. Your team may have to communicate the changes in formal training sessions, or by sharing information informally with co-workers. Written instructions, directives, and memos may also be needed as a permanent record of the change.

> Don't leave people in the dark. It is better to broadcast the change than to overlook people who need to know about it. Many people not directly involved in the process may have had to compensate for the problem in the past. They'll be glad to know about the change.

c) Update documentation to reflect the changes in the process.

- Key questions a team might address:
  - Do we need a new policy or procedures?
  - Do we need a new documentation or data collection form?

  - Who has the responsibility for updating the documentation?
  - Who has the responsibility for carrying out policy and procedures?
- Useful tools for updating documentation include:
  - Tree Diagram to assign tasks to be accomplished, the person or position responsible (*PMMJ*, p. 64 and *MJII*, p. 156)
  - Flowchart for defining processes (*MJ9000/2000*, pp. 23-25, 27-28 and *MJII*, p. 56)
  - Variance calculation sheet to record deviations from important measures (*PMMJ*, p. 138)

d) Update and conduct training.

- Key questions the team might address:
  - Does training for carrying out the newly established policy and procedures, and writing documentation exist? If not, create it and train people how to do it.
  - Who will be responsible for updating or creating training?
  - Who will deliver the training?
  - Who will be trained?
  - What proficiency levels are required? How will proficiency be tested?
- The team should make presentations to management, steering teams, or other staff as required. Use the table on the next page as a guide in preparing the team's presentation.

Areas to Address in Presenting Your Results

Your Audience	• What information is important to them? • What do they already know? • What do they need to learn from the presentation and from future training? • Tell them the purpose and goals of the plan.
The Tools You Used	• Explain your team's problem-solving journey, including the process (See Chapter 4, "Creating a Storyboard.") • Point out which tools the team used, and which ones were effective.
The Status of the Project	If the problem-solving process is not complete, answer these questions: • What have you done/accomplished so far? • What do you have left to do? • What obstacles have you encountered? • Do you have any preliminary recommendations?
Your Team	• What have team members learned about themselves and other team members? • What have team members learned about their work, the organization, and the organization's suppliers and customers?
Manage the Presentation	• Who will participate in the presentation? Try to include as many team members as is feasible. • Distribute a typed report, including handouts of supporting documentation. • Reserve and know how to use the audiovisual equipment needed for the presentation.

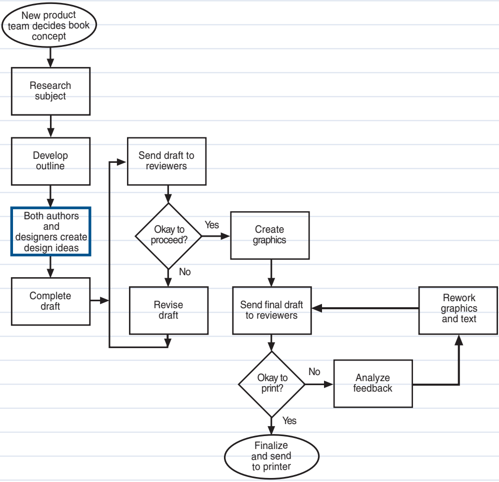
☑ Overhead slides or a computerized presentation can help focus your audience's attention on the important points of the presentation.

☑ Large amounts of data are best presented in graphs or tables. A detailed explanation of your problem-solving process and conclusions are best presented in a written handout that members of your audience can save for future reference.

ABC Team Standardizes the Improvement

Based on the results of the test of the revised process, team members felt they had implemented an effective, lasting solution to the problem of too many reworked graphics.

The team finalized the new process Flowchart, documented the standard operating procedures for the revised process, and put both the Flowchart and operating procedures on the company Intranet so that anyone could easily refer to them.



4. **Continue to monitor the process for changes.**

   Designate a process champion. This is someone who has the ongoing responsibility for monitoring process measures and reporting changes to the organization. This person should be knowledgeable about the process, its documentation, procedures, and required training.

   - Use the appropriate tools to monitor the process. (See Step 3, page 54 for a list of tools.)
   - Establish a monitoring plan for collecting data. Address these issues:
     - How much data should be collected?
     - Who will collect it?
     - How often should it be collected?
     - What records will be kept? By whom?

ABC Team Monitors the Change

The ABC team submitted its final report to the management group. This report contained a recommendation for appointing someone from management to be responsible for monitoring key performance areas to ensure that ABC was able to "hold the gain" in the new product development process and to identify other possible ways of improving the process in the future.

The team recommended that the reviews focus on the following:

- Feedback from the book reviewers on the quality of the graphics
- The number of unacceptable graphics
- The frequency and duration of delays caused by reworking unacceptable graphics

Jeremy accepted responsibility for tracking and reporting these measures at monthly management meetings.

How can I turbo-charge this step?

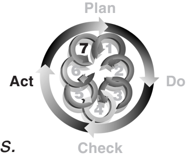
Teams should consider using these tools to help the organization, customers, and suppliers to more thoroughly understand the solution and how the change(s) will affect them.

- Use computers and Intranets for instantly communicating information.
- Use Force Field Analysis to identify the driving and restraining forces that will influence the required process change(s). (See *MJII*, p. 63.) Work on strengthening the driving forces and/or removing the restraining forces.
- Use the Affinity Diagram and the Interrelationship Digraph to organize the data and focus on the important issue(s) affecting the change. (See *MJII*, pp. 12 and 76, respectively.)
- Use the ISO 9000 Standards as a formal or informal process to standardize your processes and documentation. (See *MJ9000/2000*, pp. 19-40.)

Step 7

Reflect and Act on Learnings:

Learning from
and improving your
team's problem-solving process.



What does this step do?

Helps teams address the lessons learned from the problem-solving process and identify the next improvement opportunities.

What concepts must I understand to do this step?

Learning Organization

In a learning organization, knowledge is defined, documented, reviewed, updated, and easily available to everyone in the organization.

- The knowledge that team members and leaders have gained about what worked, what didn't work, and what needs to be done next (if anything), should be clearly understood and documented.
- When teams share their results, it helps reinforce what they learned and helps others in the organization to benefit from the team's experience so that future problem-solving efforts and team performance can be improved.

Human Dynamics and Team Spirit

To have good teams and good teamwork, team members need to:

- Continually build on their knowledge and skills.
- Build and manage cooperative relationships with others.

- Develop their skills in identifying and solving problems.
- Do what they can to create environments and processes that encourage people to excel in their work.

What actions must be taken in this step?

- Use Classic **Brainstorming**
- Construct and interpret the **Radar Chart**
- **Celebrate**!

How do I do it?

1. **Assess the problem-solving process the team used and the results achieved. Recommend changes, if needed.**
   - When teams make reflection and assessment part of the regular problem-solving process, they can avoid making costly mistakes in the future and can develop more productive ways of working.
   - Pay special attention to the processes that produced the results, not just the results.
     - How well did the problem get solved? How could it be better next time?
     - How well did the *process* for solving the problem work? How could it be better next time?
   - Assess the team's effectiveness on each part of the PDCA Cycle:
     - **Plan:** What did the team plan to do?
     - **Do:** What did the team actually do?
     - **Check:** What did the team find when they checked?
     - **Act:** What will be done about the differences?

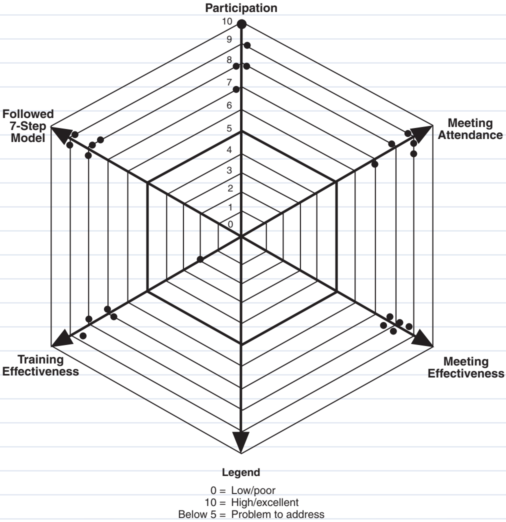
- Assess the training, if training was provided as part of the team's problem-solving process.
  - What areas need improvement (tools, process, teaming, etc.)?
  - What new areas need to be covered?
- Brainstorm a list of lessons learned. What did you learn about:
  - Yourself as an individual?
  - Yourself as a team player?
  - Your customers?
  - Your organization?

To assess the team's effectiveness or the team's processes, consider using the Radar Chart (*MJII*, p. 137.) This tool allows a team to assess multiple performance areas and quickly illustrates to the team what's going well, what needs improvement, and if there are gaps in team members' perceptions.

ABC Team Evaluates the Experience

The ABC team had a final meeting to conduct a self-assessment on how it performed as a team and to identify areas that needed to be addressed in the future by other problem-solving teams.

The team used a Radar Chart to assess five areas of performance, on a scale of 0–10, with 0 equal to "non-functioning" and 10 equal to "excellent." Individual team member scores for the five areas of performance are illustrated in the chart below.



ABC Team Evaluates the Experience, continued

The team looked for clustered scores to see where members were in agreement and for extreme scores (high and low) to understand why members were not in agreement. The lowest score was a “2” for “Training Effectiveness,” while the other scores for that category were “7” or higher. Stephano, who assigned the “2,” explained that he rated it so low because he already knew the subject matter fairly well and didn’t need the training. After the training was over, he admitted to himself that he could have probably helped the team more by using that time to do research or other work.

In light of this, the team made a recommendation to Delaney, the Director of Human Resources, to improve the department’s process for determining training needs by providing staff with more detailed information about course objectives and content.

The highest score of “10” was given to “Participation,” while the other scores for that category ranged only as low as “7.” Lani, who assigned the “10,” said that in the past she had worked almost exclusively by herself and this was a refreshing change that resulted in one of the best work experiences that she had in years.

Team members congratulated themselves for having only one score below “5,” which they used as a cut-off point to indicate a serious problem or area needing attention.

2. **Continue the improvement process where needed; standardize where possible.**
   - Continue talking with customers.
   - Seek other opportunities for improvement. Consider reviewing the team's Pareto Chart (from Step 1) to select the next problem area to focus on.
   - Consider new problems that were identified during the problem-solving process but were put on a "to do" list (or "parking lot"). These problems may have been put in the parking lot because they:
     - Did not relate to the problem being addressed.
     - Were beyond the scope or capability of the team. If this is true, charter a new team to address the problem or refer the problem to management or an improvement steering team.

3. **Celebrate success.**
   - Celebrate the contribution of team members and everyone else inside or outside of the organization that supported the team's efforts. It helps to reinforce the positive feelings that come from working together to solve problems.
   - There are many ways to celebrate: Hold a party…go out to lunch…say "thank you"…present a small gift…recognize participants' successes in front of their peers. However your team chooses to celebrate, make sure it will be enjoyable for everyone.

ABC Team Celebrates

The ABC team celebrated by hosting a luncheon. Team members, the project sponsor, the company president, key suppliers and customers, and a photographer were invited. Each team member received a gift desk set embossed with the project name and start and end dates.

How can I turbo-charge this step?

- Use the Intranet to post the team's learnings. This communication will contribute to the maintenance of a learning organization.
- Recognize and reward people for their work.

Chapter Four

Creating a Storyboard

What does a storyboard do?

A storyboard is a self-explanatory, graphic summary of the key analyses, decisions, and actions of the problem-solving process. It keeps the organization informed of the team's progress during the Plan, Do, Check, and Act steps.

What concepts must I understand to create a storyboard?

- How the team's problem-solving effort addresses a customer-related problem.
- The team's purpose and objectives (the problem statement).
- How the team used the tools, and what actions were taken to address the problem.
- Who was involved in the problem-solving process.
- What data were collected, and how the team interpreted the data.
- The proposed solution.
- The targets, milestones, and results of the project.

What actions need to be taken to create an effective storyboard?

- **Summarize** the team's **activities and results** so that the storyboard text is simple, clear, and interesting to non-team members.
- **Create graphs and charts** that are accurate and easy to understand.

- **Present information** for quick understanding, using photographs, drawings, cartoons, and other graphics.
- **Organize information** to show the sequence of events and actions as they occurred during the problem-solving process.
- **Show the relevance** of the team's objectives to the organization's objectives.

How do I create a storyboard?

1. **Assemble the materials and people needed to create the storyboard.**
    - Have ready:
        - A corkboard, whiteboard, or other flat surface you can post paper on
        - Index cards or Post-it ™ Notes
        - Pushpins or tape
        - Colored markers or pens
        - Camera
        - Computer
    - Use these supplies to capture your team's ideas and results during meetings.

> The ideal storyboarding topic is a project or initiative that has a fixed timeframe, affects and involves people, improves something, e.g., a process, product, culture, technology, and shows measurable change.

- Choose a team member to record information for the storyboard.

2. **Post the storyboard where it will be visible to everyone in the organization.**
   - Use the storyboard to chart progress and to keep others informed.
   - Display the storyboard on a commonly used bulletin board, meeting room, or other heavily used public wall space.
   - Consider using the company's Intranet to post the storyboard.

> When your team is deciding the methods for creating and displaying the storyboard, bear in mind the likely duration of the problem-solving process, the wear and tear the storyboard will receive, and the confidentiality requirements of your organization. Also consider what areas in your organization need to know about your team's efforts.

3. **Develop the storyboard.**
   - The storyboard your team creates can be developed either *during or after* the implementation of the process improvement effort.
   - Post the problem statement on the storyboard.
   - Post information about the team, such as team member names, roles, and tasks assigned.
   - Summarize the work that is completed in each step or sub-step of the problem-solving process.
     - Avoid jargon and explain technical terms.
     - Keep the graphics and text simple so that everyone in the organization can understand the storyboard.

- Highlight the results of each step. Use photographs, graphs, and data wherever possible rather than narrative.
- Clearly show any improvement in the problem area selected, and the team's and organization's measures of success.
- Mention what the team has learned about teamwork, a particular process, the organization, its suppliers, and its customers.

Make the graphics easy to understand by simplifying the design of the chart (not the data). Full grids are rarely needed, and use shades of gray rather than patterned fill. Avoid the use of legends whenever possible. Instead, write labels on the graph itself.

When you present your results, make sure you order the data in ways that serve your purpose. Ask "What is the trend we want to show?" This trend may not be the order in which you collected the data.

How can I turbo-charge the storyboarding process?

- Display the storyboard during meetings to focus the team on the improvement effort. Storyboards also help maintain continuity when team membership changes.
- Consider using a software package to generate and store the storyboard.

Handy Checklist for Creating an Effective Storyboard

Ask...	Check for Yes
Does it describe the problem?	☐ Describes the team's task and why the problem was chosen.
Does it address a customer-related problem?	☐ Shows the relevance of the team's objectives to the organization's objectives.
Is it interesting?	☐ Uses photos, graphics, cartoons, and humor, when appropriate.
Is it clear to people at all levels?	☐ Explains abbreviations and technical terms, avoids jargon, graphics and text are clear.
Does it explain what actions were taken?	☐ Shows what was done, why, when, by whom, and how. Shows the correct usage of the tools. Captures best practice.
Does it logically describe the sequence of actions taken?	☐ Follows a logical, problem-solving process.
Does it clearly show improvement in the problem areas selected?	☐ Reports on clear measures of success in relation to the team's and organization's objectives. Includes intangible improvements. Mentions what the team has learned.
Are the metrics clearly shown on the graphs?	☐ Clearly labels the x and y axes of graphs with the measures used, e.g., number of complaints, monthly sales in dollars, percent of goods returned.

Storyboard Example

The Situation

The Browning Elementary School District recently finished a four-year building project, which combined two smaller schools into one for grades K-6. Now that the space needs of its growing student population had been met, the staff and administration felt that they should address other important issues.

For the first time, the annual survey of its stakeholders showed a decrease in satisfaction. School board meetings had come to be dominated by parents and teachers unhappy with the educational programs.

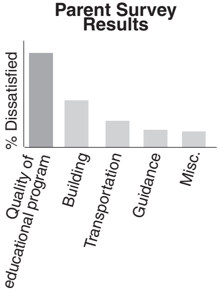
The administration decided to form a team to improve the quality of the education program, and planned a follow-up survey of stakeholders. The 2nd survey revealed that although parents and students were very happy with the building and equipment, they were not happy with the existing physical education (PE) program.

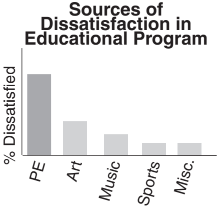
Jim Hoyt, the school's physical education teacher, led the team's effort to improve the PE program.

Artwork courtesy of Sharon McCarty

Step 1. Describe the Problem

Problem Statement: There is a high percentage of children who are dissatisfied with PE class.
Reason selected: A follow-up survey revealed that dissatisfaction with the PE program was a major cause of the growing dissatisfaction with the educational program.





Team Members

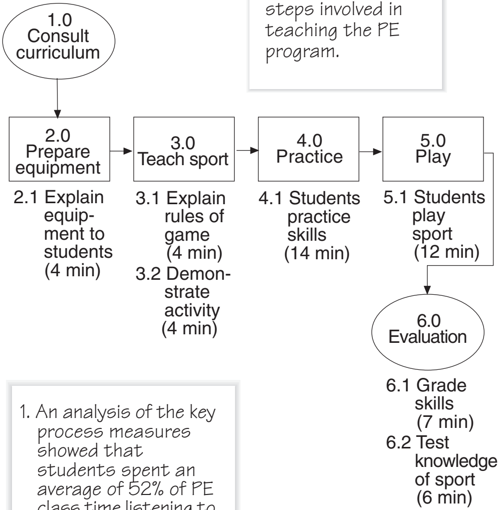
1. Jim Franks, school board chairman
2. Janice Woo, principal
3. Tom Herron, staff
4. Sue Rossi, school board member
5. Albert Gupta, parent
6. Frank Smith, parent

Milestones

- Team formed. First problem statement written, distributed (9/12).
- Storyboard begun.
- Problem statement revised, distributed to team, school staff, school board (10/14).

Step 2. Describe the Current Process

There are 6 major steps involved in teaching the PE program.



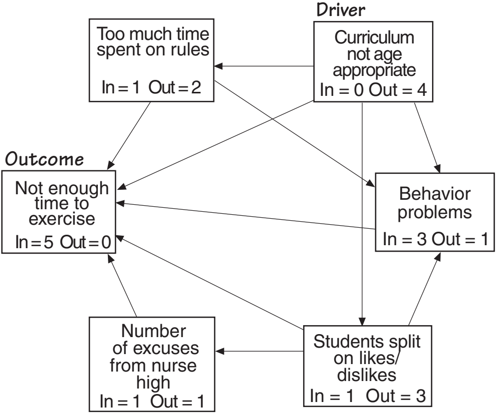
1. An analysis of the key process measures showed that students spent an average of 52% of PE class time listening to the teacher or waiting for a turn to practice. **Exercise time is below requirements.**
2. Number of excuses from nurse high compared to other classes.
3. Incidents of behavior problems high.

Milestones

- Flowchart of process created (10/19).
- Checksheets of key process measures analyzed (time spent in each activity) (10/22).

Step 3. Identify the Root Cause(s) of the Problem

Problem: Number of students who are dissatisfied with PE class is high.



Students are frustrated by the small amount of time they actually spend exercising. This was caused by **a curriculum that had been stretched to fit too many students of different ages** (1/24).

Milestones

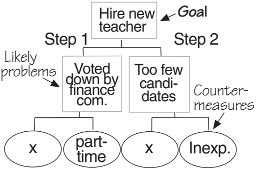
- Focus group formed, collected comments and data (11/1).
- Interrelationship Digraph created and verified (11/5).

Step 4. Develop a Solution and Action Plan

The team brainstormed possible solutions to the problem, and possible criteria to weigh the options. The option of hiring a teacher who will modify the curriculum for grades 4-6 is selected.

Options / Criteria	Use recess time for PE	Classroom teachers teach PE	**Add new teacher**
Effectiveness (.15)	.54 x .15 (.08)	.33 x .15 (.05)	.01 x .15 (0)
Feasibility (.28)	.01 x .28 (0)	.37 x .28 (.10)	.37 x .28 (0)
Benefit to whole organization (.55)	.01 x .55 (.01)	.10 x .55 (.06)	.49 x .55 (.27)
Cost (.02)	.01 x .02 (0)	.22 x .02 (0)	.12 x .02 (0)
Total	.09	.21	**.37**

Then the team brainstormed possible countermeasures for potential problems. Options of hiring a part-time teacher and inexperienced candidate are selected.



x = Difficult
Part-time teacher, inexperienced candidate selected

Milestones

- The school board chairman presented a written proposal to the school board, plan approved (3/5).
- The school board added the salary expenses to the proposed budget, finance committee approved it. Monitoring plan created.
- Jim Rudolph replaces team member Sue Rossi (3/16).

Step 5. Implement the Solution

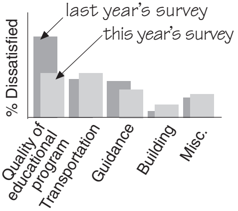
Project Plan Area	Project Plan	Actual Results	Variance	Reason
Schedule				
Advertise opening	4/12	4/12	0	
Interview 6 people/ make offer	4/25	4/26 (4 exper. candidates)	1 day	Tight labor market
Modify curriculum	10/2	10/1	1 day	
Re-survey parents	6/3	6/5	2 days	Copier broke
Budget				
Advertising expenses	$2,500	$2,700	$200	Used Web to advertise
Survey expenses	$150	$150	0	

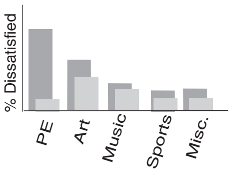
The new teacher was hired on schedule. The advertising and survey expenses were just above budget. Curriculum was modified on schedule.

Milestones

- Finance committee approved proposed budget with some debate (3/16).
- Offer accepted, new hire began at the start of the new school year with a one-year contract (6/14).
- Principal, team approved new curriculum (10/1).

Step 6. Review and Evaluate the Results of the Change


Annual Survey

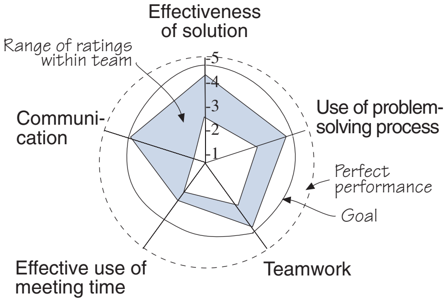

2nd Survey of Program Areas

1. 65% of the annual surveys are returned, showing 25% improvement in satisfaction with overall quality.
2. 2nd survey of program areas shows 60% decrease in dissatisfaction with PE program.
3. Number of behavior problems reported to principal is reduced by 20%.
4. Number of excuses from nurse decreases 10%.

Milestones

- Team sent survey results and a letter to the school board recommending that the new teacher be retained permanently (10/4).
- Team presented survey results at a school board meeting (10/7).
- Team leader wrote parent newsletter article describing curriculum changes and the results of the survey (10/7).

Step 7. Reflect and Act on Learnings



1. Two causes for the wide range of scores on communication were uncovered in discussion:
   a. Many teachers were uncomfortable making the results of the surveys public. They felt that it was too similar to a performance evaluation, and therefore should be kept confidential.
   b. There was also concern about the team's knowledge of how to measure stakeholder satisfaction. **A new sub-team was created to improve the survey process** (Woo, Franks, Grant).
2. The team agreed that the storyboard helped maintain continuity as team membership changed over the two years of the process, but better communication was needed between the parents and the team.
3. **Plans for the future**: Reduce the impact of cuts in the arts program.

Milestones

- Team played a softball game and had a picnic lunch to celebrate!

Storyboarding References

Forsha, Harry I. *Show Me: The Complete Guide to Storyboarding and Problem Solving*. Milwaukee, WI: ASQ Press, 1995.

Raymond, Larry. *Reinventing Communication: A Guide to Using Visual Language for Planning, Problem Solving, and Reengineering*. Milwaukee, WI: ASQ Press, 1994.

Ritter, Diane and Michael Brassard. *The Creativity Tools Memory Jogger*™. Salem, NH: GOAL/QPC, 1998, 165–167.

Tufte, Edward R. *Envisioning Information*. Cheshire, CT: Graphics Press, 1990.

Types of Measures

Measure	Description
Quality	Key product or service characteristics of interest to you and the customer: mistakes, failures, complaints, returned items, repairs, time, etc.
People	Information about the people doing the job that will impact performance or product: grade level, age, experience, skill, individual.
Equipment	Equipment used to produce product or service: computers, heavy equipment, presses, copiers, phones, buses, ovens, tools, instruments–by kind, manufacturer, lot, etc.
Material	Materials that go into the product or service: electronic components, paper, solvent, resin, paints, books, videos, pens–by kind, manufacturer, lot, etc.
Procedure	How things are done or carried out: what conditions, methods, orders, arrangement, etc.
Environment	Conditions around the process that might impact the quality of product or service: building, room, temperature.
Cost	Time, expenses, staffing.
Delivery	What may impact delivery of the product or service to your customer: instructions, shortages, defaults in payments, delays in delivery, wait time.

Continued on next page

Types of Measures, continued

Measure	Description
Safety	Accidents, mistakes, breakdowns.
Reliability	The ability to produce the services promised, dependably and accurately.
Responsiveness	The wilingness to help customers and provide prompt service.
Courtesy	Politeness, respect, consideration, and friendliness.
Competence	Having the skills and knowledge needed to perform the service customers desire.
Credibility	Being a service provider that is trustworthy, believable, and honest.
Accessibility	Ease of access and ease of contact.
Communication	Verbal interactions with the customers—keeping customers informed, using language they understand, and listening to them and their concerns.
Understanding	Finding out the needs, expectations, and satisfaction levels of the customers.
Tangibles	The physical facilities in which the service is provided, the equipment used in its delivery, the appearance of the service personnel, and the materials used to communicate.

Advanced Techniques Resource List

This appendix contains brief descriptions and references to more advanced techniques for problem solving. In-depth descriptions of these methods are beyond the scope of this book. However, readers who want to refine their problem-solving skills can refer to the resources listed below.

Design of Experiments

A statistical process for determining the effects of changes that are introduced into a process under controlled conditions. The purpose of the experimentation is to make a process more robust by reducing possible sources of variation that could destabilize the process.

Taguchi, Genichi and Yoshiko Yokoyama. *Taguchi Methods: Design of Experiments*. Quality Engineering, Volume 4. Novi, MI: American Supplier Institute, 1993.

Barrentine, Larry B. *An Introduction to Design of Experiments: A Simplified Approach*. Milwaukee, WI: ASQ Press, 1999.

Failure Mode and Effect Analysis

An analytical process, usually conducted during product development, in which potential product defects and problems with use are identified and evaluated for severity. Once failure modes have been identified, design modifications are made to eliminate these sources of failure.

Stamatis, D. H. *Failure Mode and Effect Analysis: FMEA from Theory to Execution*. Milwaukee, WI: ASQ Press, 1995.

McDermott, Robin E., Raymond J. Mikulak, and Michael R. Beauregard. *The Basics of FMEA*. New York, NY: Quality Resources, 1996.

Is/Is Not Analysis

An analytical technique for identifying and validating the root cause of a problem. The analysis involves the identification of distinctive features in the problem condition (where it "is") that do not appear where the problem condition does not exist (where it "is not"). These distinctions are possible causes of the problem and are subjected to further testing to verify the true root cause of the problem.

Kepner, Charles, and Benjamin Tregoe. *The New Rational Manager*. Princeton, NJ: Princeton Research Press, 1981. (See Chapter 2.)

Six Sigma Quality

Six sigma quality is both a philosophy and a methodology in which an organization continuously improves its processes until they are virtually defect-free. Six sigma is a statistically derived measure of a process that consistently produces no more than 3.4 defects (or failures) for every one million outputs. The higher the sigma level, the lower the defect rate, e.g., a "one sigma process" produces 32% defects, a "two sigma process," 5% defects, a "three sigma process" 0.3%, and a "six sigma process" is 99.9997% defect-free.

Harry, Mikel J. *The Nature of Six Sigma Quality*. Schaumburg, IL: Motorola University Press, 1997.

Breyfogle, Forrest W. *Implementing Six Sigma: Smarter Solutions Using Statistical Methods*. New York, NY: John Wiley & Sons, Inc., 1999.

TRIZ

TRIZ, which in Russian stands for “Theory of Inventive Problem Solving,” is a systematic approach for creating innovative solutions to technical problems. It is especially useful for new product development, service delivery, and solving production problems.

Genrich S. Altshuller and others devoted more than 50 years of research into understanding how inventive or breakthrough solutions were found. This research defined 11 conceptual elements that have been used to solve problems and produce patentable solutions.

Altshuller, Genrich S. *40 Principles: TRIZ Keys to Technical Innovation*. Worcester, MA: Technical Innovation Center, Inc., 1997.

Altshuller, Genrich S. *The Innovation Algorithm: TRIZ Systematic Innovation and Technical Creativity*. Worcester, MA: Technical Innovation Center, Inc., 1999.

GOAL/QPC Research Committee. *TRIZ Research Report: An Approach to Systematic Innovation*. Salem, NH: GOAL/QPC, 1997.

Appendix C

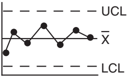
Control Charts—Recognizing Sources of Variation

This appendix describes how to construct and interpret several types of Control Charts. The information is reproduced from *The Memory Jogger™ II*, pp. 36–51.

For additional information on Control Charts, consult the *Coach's Guide to The Memory Jogger™ II*, pp. 45–62 or the Control Chart guides available as part of *The Memory Jogger™ II Off-the-Shelf Modular Training Materials*.

Control Charts

Recognizing sources of variation



Why use it?

To monitor, control, and improve process performance over time by studying variation and its source.

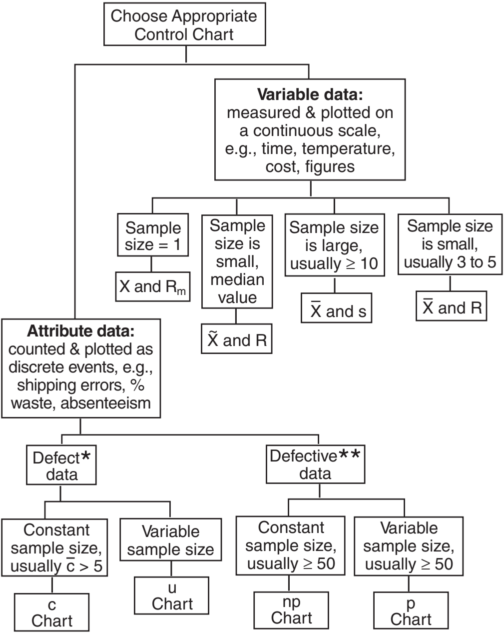
What does it do?

- Focuses attention on detecting and monitoring process variation over time
- Distinguishes special from common causes of variation, as a guide to local or management action
- Serves as a tool for ongoing control of a process
- Helps improve a process to perform consistently and predictably for higher quality, lower cost, and higher effective capacity
- Provides a common language for discussing process performance

How do I do it?

There are many types of Control Charts. The Control Chart(s) that your team decides to use will be determined by the type of data you have. Use the Tree Diagram on the next page to determine which Control Chart(s) will best fit your situation. Other types of Control Charts, which are beyond the scope of this book, include the Pre-Control Chart, the Moving Average & Range Chart, the Cumulative Sum Chart, and Box Plots.

Based on the type of data and sample size you have, choose the appropriate Control Chart.



* Defect = Failure to meet one of the acceptance criteria. A defective unit might have multiple defects.

** Defective = An entire unit fails to meet acceptance criteria, regardless of the number of defects on the unit.

Constructing Control Charts

1. **Select the process to be charted.**

2. **Determine sampling method and plan.**
   - How large a sample can be drawn? Balance the time and cost to collect a sample with the amount of information you will gather. ***See the Tree Diagram on the previous page for suggested sample sizes.***
   - As much as possible, obtain the samples under the same technical conditions: the same machine, operator, lot, and so on.
   - Frequency of sampling will depend on whether you are able to discern patterns in the data. Consider hourly, daily, shifts, monthly, annually, lots, and so on. Once the process is "in control," you might consider reducing the frequency with which you sample.
   - Generally, collect 20–25 groups of samples before calculating the statistics and control limits.
   - Consider using historical data to set a baseline.

   Tip Make sure samples are random. To establish the inherent variation of a process, allow the process to run untouched, i.e., according to standard procedures.

3. **Initiate data collection.**
   - Run the process untouched, and gather sampled data.
   - Record data on an appropriate Control Chart sheet or other graph paper. Include any unusual events that occur.

4. Calculate the appropriate statistics.

a) If you have attribute data, use the Attribute Data Table, Central Line column.

Attribute Data Table

Type Control Chart	Sample size	Central Line	Control Limits
Fraction defective p Chart	Variable, usually ≥50	For each subgroup: $p = np/n$ For all subgroups: $\bar{p} = \Sigma np/\Sigma n$	$^*UCL_p = \bar{p} + 3\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$ $^*LCL_p = \bar{p} - 3\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$
Number defective np Chart	Constant, usually ≥50	For each subgroup: np = # defective units For all subgroups: $n\bar{p} = \Sigma np/k$	$UCL_{np} = n\bar{p} + 3\sqrt{n\bar{p}(1 - \bar{p})}$ $LCL_{np} = n\bar{p} - 3\sqrt{n\bar{p}(1 - \bar{p})}$
Number of defects c Chart	Constant	For each subgroup: c = # defects For all subgroups: $\bar{c} = \Sigma c/k$	$UCL_c = \bar{c} + 3\sqrt{\bar{c}}$ $LCL_c = \bar{c} - 3\sqrt{\bar{c}}$
Number of defects per unit u Chart	Variable	For each subgroup: $u = c/n$ For all subgroups: $\bar{u} = \Sigma c/\Sigma n$	$^*UCL_u = \bar{u} + 3\sqrt{\frac{\bar{u}}{n}}$ $^*LCL_u = \bar{u} - 3\sqrt{\frac{\bar{u}}{n}}$

np = # defective units
c = # of defects
n = sample size within each subgroup
k = # of subgroups

* This formula creates changing control limits. To avoid this, use average sample sizes $\bar{n}$ for those samples that are within ±20% of the average sample size. Calculate individual limits for the samples exceeding ±20%.

b) If you have variable data, use the Variable Data Table, Central Line column.

Variable Data Table

Type Control Chart	Sample size n	Central Line*	Control Limits
Average & Range	<10, but usually 3 to 5	$\bar{\bar{X}} = \frac{(\bar{X}_1+\bar{X}_2+\ldots\bar{X}_k)}{k}$	$UCL_{\bar{x}} = \bar{\bar{X}} + A_2\bar{R}$ $LCL_{\bar{x}} = \bar{\bar{X}} - A_2\bar{R}$
$\bar{X}$ and R		$\bar{R} = \frac{(R_1+R_2+\ldots R_k)}{k}$	$UCL_R = D_4\bar{R}$ $LCL_R = D_3\bar{R}$
Average & Standard Deviation	Usually ≥10	$\bar{\bar{X}} = \frac{(\bar{X}_1+\bar{X}_2+\ldots\bar{X}_k)}{k}$	$UCL_{\bar{X}} = \bar{\bar{X}} + A_3\bar{s}$ $LCL_{\bar{X}} = \bar{\bar{X}} - A_3\bar{s}$
$\bar{X}$ and s		$\bar{s} = \frac{(s_1+s_2+\ldots s_k)}{k}$	$UCL_s = B_4\bar{s}$ $LCL_s = B_3\bar{s}$
Median & Range	<10, but usually 3 or 5	$\bar{\tilde{X}} = \frac{(\tilde{X}_1+\tilde{X}_2+\ldots\tilde{X}_k)}{k}$	$UCL_{\tilde{X}} = \bar{\tilde{X}} + \tilde{A}_2\bar{R}$ $LCL_{\tilde{X}} = \bar{\tilde{X}} - \tilde{A}_2\bar{R}$
$\tilde{X}$ and R		$\bar{R} = \frac{(R_1+R_2+\ldots R_k)}{k}$	$UCL_R = D_4\bar{R}$ $LCL_R = D_3\bar{R}$
Individuals & Moving Range	1	$\bar{X} = \frac{(X_1+X_2+\ldots X_k)}{k}$	$UCL_X = \bar{X} + E_2\bar{R}_m$ $LCL_X = \bar{X} - E_2\bar{R}_m$
X and R_m		$R_m = \lvert(X_{i+1} - X_i)\rvert$ $\bar{R}_m = \frac{(R_1 + R_2 + \ldots R_{k-1})}{k-1}$	$UCL_{Rm} = D_4\bar{R}_m$ $LCL_{Rm} = D_3\bar{R}_m$

k = # of subgroups, $\tilde{X}$ = median value within each subgroup

$*\bar{X} = \frac{\Sigma X_i}{n}$

5. **Calculate the control limits.**

   a) If you have attribute data, use the Attribute Data Table, Control Limits column.

   b) If you have variable data, use the Variable Data Table, Control Limits column for the correct formula to use.

   - Use the Table of Constants to match the numeric values to the constants in the formulas shown in the Control Limits column of the Variable Data Table. The values you will need to look up will depend on the type of Variable Control Chart you choose and on the size of the sample you have drawn.

   Tip If the Lower Control Limit (LCL) of an Attribute Data Control Chart is a negative number, set the LCL to zero.

   Tip The p and u formulas create changing control limits if the sample sizes vary subgroup to subgroup. To avoid this, use the average sample size, n, for those samples that are within ±20% of the average sample size. Calculate individual limits for the samples exceeding ±20%.

6. **Construct the Control Chart(s).**

   - For Attribute Data Control Charts, construct one chart, plotting each subgroup's proportion or number defective, number of defects, or defects per unit.
   - For Variable Data Control Charts, construct two charts: on the top chart plot each subgroup's mean, median, or individuals, and on the bottom chart plot each subgroup's range or standard deviation.

Table of Constants

Sample size n	$\bar{X}$ and R Chart			$\bar{X}$ and s Chart			
	A_2	D_3	D_4	A_3	B_3	B_4	c_4*
2	1.880	0	3.267	2.659	0	3.267	.7979
3	1.023	0	2.574	1.954	0	2.568	.8862
4	0.729	0	2.282	1.628	0	2.266	.9213
5	0.577	0	2.114	1.427	0	2.089	.9400
6	0.483	0	2.004	1.287	0.030	1.970	.9515
7	0.419	0.076	1.924	1.182	0.118	1.882	.9594
8	0.373	0.136	1.864	1.099	0.185	1.815	.9650
9	0.337	0.184	1.816	1.032	0.239	1.761	.9693
10	0.308	0.223	1.777	0.975	0.284	1.716	.9727

Sample Size n	$\tilde{X}$ and R Chart			X and R_m Chart			
	$\tilde{A}_2$	D_3	D_4	E_2	D_3	D_4	d_2*
2	- - - -	0	3.267	2.659	0	3.267	1.128
3	1.187	0	2.574	1.772	0	2.574	1.693
4	- - - -	0	2.282	1.457	0	2.282	2.059
5	0.691	0	2.114	1.290	0	2.114	2.326
6	- - - -	0	2.004	1.184	0	2.004	2.534
7	0.509	0.076	1.924	1.109	0.076	1.924	2.704
8	- - - -	0.136	1.864	1.054	0.136	1.864	2.847
9	0.412	0.184	1.816	1.010	0.184	1.816	2.970
10	- - - -	0.223	1.777	0.975	0.223	1.777	3.078

* Useful in estimating the process standard deviation $\hat{\sigma}$.

Note: The minimum sample size in this chart is 2 because variation in the form of a range can only be calculated in samples greater than 1. The X and R_m Chart creates these minimum samples by combining and then calculating the difference between sequential, individual measurements.

- Draw a solid horizontal line on each chart. This line corresponds to the process average.
- Draw dashed lines for the upper and lower control limits.

Interpreting Control Charts

- **Attribute Data Control Charts** are based on one chart. The charts for fraction or number defective, number of defects, or number of defects per unit, measure variation *between samples*. **Variable Data Control Charts** are based on two charts: the one on top, for averages, medians, and individuals, measures variation *between subgroups* over time; the chart below, for ranges and standard deviations, measures variation *within subgroups* over time.
- Determine if the process mean (center line) is where it should be relative to your customer specifications or your internal business needs or objectives. If not, then it is an indication that something has changed in the process, or the customer requirements or objectives have changed.
- Analyze the data relative to the control limits; distinguishing between *common* causes and *special* causes. The fluctuation of the points within the limits results from variation inherent in the process. This variation results from common causes within the system, e.g., design, choice of machine, preventive maintenance, and can only be affected by changing that system. However, points outside of the limits or patterns within the limits, come from a special cause, e.g., human errors, unplanned events, freak occurrences, that is not part of the way the process normally operates, or is present because of an unlikely combination of process

steps. Special causes must be eliminated before the Control Chart can be used as a monitoring tool. Once this is done, the process will be "in control" and samples can be taken at regular intervals to make sure that the process doesn't fundamentally change. See "Determining if Your Process is Out of Control."

- Your process is in "statistical control" if the process is not being affected by special causes, the influence of an individual or machine. All the points must fall within the control limits and they must be randomly dispersed about the average line for an in-control system.

Tip "Control" doesn't necessarily mean that the product or service will meet your needs. It only means that the process is *consistent.* Don't confuse control limits with specification limits—specification limits are related to customer requirements, not process variation.

Tip Any points outside the control limits, once identified with a cause (or causes), should be removed and the calculations and charts redone. Points within the control limits, but showing indications of trends, shifts, or instability, are also special causes.

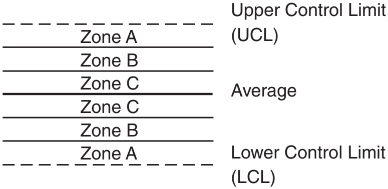
Tip When a Control Chart has been initiated and all special causes removed, continue to plot new data on a new chart, but DO NOT recalculate the control limits. As long as the process does not change, the limits should not be changed. Control limits should be recalculated only when a permanent, desired change has occurred in the process, and only using data *after* the change occurred.

Tip Nothing will change just because you charted it! You need to do something. Form a team to investigate. See “Common Questions for Investigating an Out-of-Control Process.”

Determining if Your Process is “Out of Control”

A process is said to be “out of control” if either one of these is true:

1. **One or more points fall outside of the control limits**
2. **When the Control Chart is divided into zones, as shown below, any of the following points are true:**



   a) Two points, out of three consecutive points, are on the same side of the average in Zone A or beyond.

   b) Four points, out of five consecutive points, are on the same side of the average in Zone B or beyond.

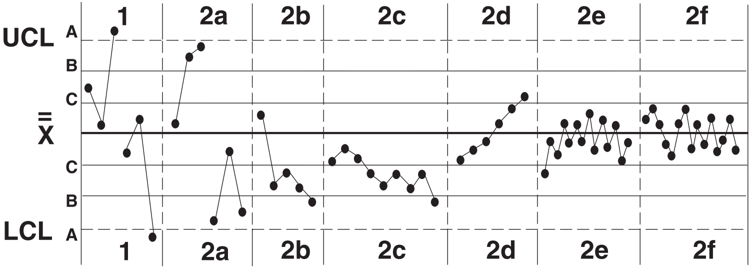
   c) Nine consecutive points are on one side of the average.

   d) There are six consecutive points, increasing or decreasing.

   e) There are fourteen consecutive points that alternate up and down.

   f) There are fifteen consecutive points within Zone C (above and below the average).

Tests for Control



Source: Lloyd S. Nelson, Director of Statistical Methods, Nashua Corporation, New Hampshire

Common Questions for Investigating an Out-of-Control Process

☐ Yes ☐ No Are there differences in the measurement accuracy of instruments/methods used?

☐ Yes ☐ No Are there differences in the methods used by different personnel?

☐ Yes ☐ No Is the process affected by the environment, e.g., temperature, humidity?

☐ Yes ☐ No Has there been a significant change in the environment?

☐ Yes ☐ No Is the process affected by predictable conditions? Example: tool wear.

☐ Yes ☐ No Were any untrained personnel involved in the process at the time?

☐ Yes ☐ No Has there been a change in the source for input to the process? Example: raw materials, information.

☐ Yes ☐ No Is the process affected by employee fatigue?

☐ Yes ☐ No Has there been a change in policies or procedures? Example: maintenance procedures.

☐ Yes ☐ No Is the process adjusted frequently?

☐ Yes ☐ No Did the samples come from different parts of the process? Shifts? Individuals?

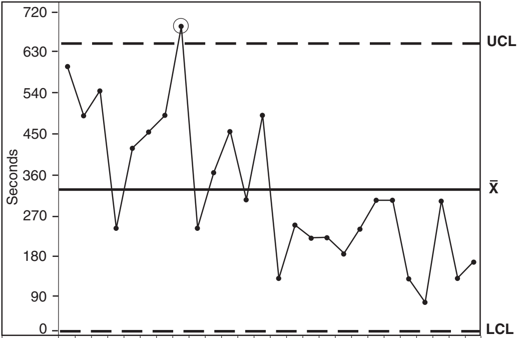
☐ Yes ☐ No Are employees afraid to report "bad news"?

A team should address each "Yes" answer as a potential source of a special cause.

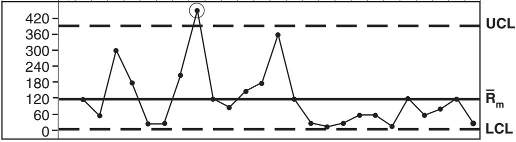
Individuals & Moving Range Chart

IV Lines Connection Time

Process/Operation: IV Lines Connection Open Heart Admissions			**Department:** Intensive Care
Characteristic: Time in seconds	**Sample Size:** One	**Sample Frequency:** Each patient	**By:** EW **Date:** 6/10
Individuals: k = 26	∑**X** = 8470	$\bar{\bar{X}}$ = 325.77 **UCL** = 645	**LCL** = 7
Ranges: n = 2	∑**R** = 2990	$\bar{R}$ = 119.6 **UCL** = 392	**LCL** = 0



X	600	480	540	240	420	450	480	690	240	360	450	300	480	120	240	210	210	180	240	300	300	130	120	300	180	210
R_m	—	120	60	300	180	30	30	210	450	120	90	150	180	360	120	30	0	30	60	60	0	120	60	80	120	30
Who?	EW	EW	EW	EW	EW	EW	EW	EW	MA	EW	EW	EW	EW	EW	EW	EW	MA	EW	EW	EW	EW	EW	EW	EW	EW	EW
When?	4/9	11	12	13	25	30	5/2	3	4	5	9	13	14	14	16	17	19	20	22	23	23	24	30	30	6/6	6



Information provided courtesy of
Parkview Episcopal Medical Center

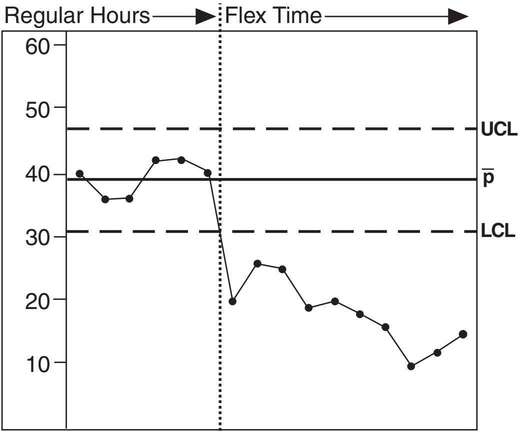
Note: Something in the process changed, and now it takes less time to make IV connections for patients being admitted for open heart surgery.

p Chart

General Dentistry: Percent of Patients Who Failed to Keep Appointments

Historical Statistics:

$\bar{p}$ = 39 **UCL** = 47 **LCL** = 31



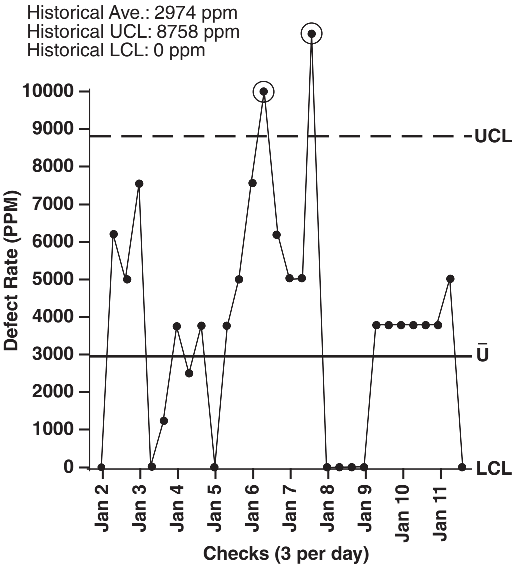
% Failed	40	36	36	42	42	40	20	26	25	19	20	18	16	10	12	12
Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Year	1992						1993									

Information provided courtesy of U.S. Navy, Naval Dental Center, San Diego

Note: Providing flex time for patients resulted in fewer appointments missed.

u Chart

Shop Process Check
Solder Defects


Historical Ave.: 2974 ppm
Historical UCL: 8758 ppm
Historical LCL: 0 ppm

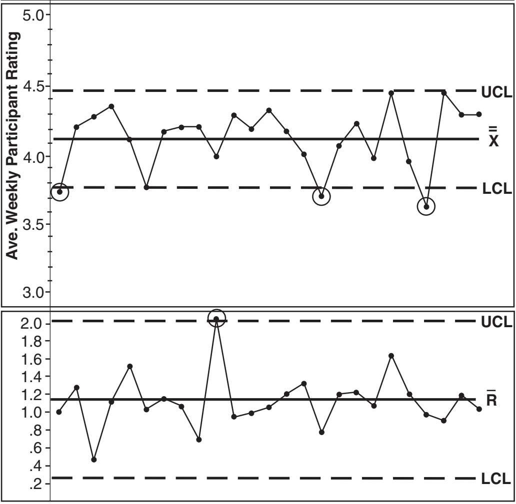
Information provided courtesy of AT&T

$\overline{X}$ & R Chart

Overall Course Evaluations

n = 10 evaluations randomly sampled each week
1-Not at all 2-Not very 3-Moderately 4-Very 5-Extremely

Wk #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Ave.
$\overline{X}$	3.76	4.21	4.29	4.36	4.13	3.77	4.17	4.21	4.22	4.00	4.30	4.20	4.32	4.18	4.02	3.71	4.08	4.23	3.98	4.46	3.96	3.63	4.48	4.30	4.29	4.13
R	1.01	1.27	0.48	1.32	1.52	1.03	1.15	1.07	0.70	2.05	0.95	0.99	1.06	1.21	1.33	0.78	1.21	1.23	1.08	1.64	1.20	0.98	0.91	1.19	1.03	1.14



Information provided courtesy of Hamilton Standard

Note: Weeks 1, 10 (from bottom chart), 16, and 22 should be reviewed to understand why the ratings are outside the control limits.

Index

GOAL QPC

IMPROVING THE WAY ORGANIZATIONS RUN

GOAL QPC

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PROJECT MANAGEMENT MEMORY JOGGER™

A Pocket Guide for Project Teams

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IMPROVING THE WAY ORGANIZATIONS RUN

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Paula Martin
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Lisa Gilliland, *Marketing*
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Printed in the United States of America

First Edition
10 9 8

ISBN 1-57681-001-1

Acknowledgments

We thank the following people for their comments, knowledge, and inspiration throughout the development of this product.

Matthew Booth &
Pam Burton
Scudder Stevens & Clark

D'Anne Carpenter &
Diane Evangelista
Mercy Health Services

Roland Chapell
Northrop Grumman

Charlotte Chase
New Venture Gear, Inc.

Mark Daniel
Inco Ltd.

Ellen Domb
PQR Group

Connie Emerson
CJM Associates

Susan Engelkemeyer
Babson College

Bea Glenn
Chiquita Brands International

Dave Haskett
Johnson Controls, Inc.

Susan Hillenmeyer
Belmont University

LuAnn Irwin
Eastman Kodak

Paul Jones
Procter & Gamble

Rod Lincoln
Cytec Industries

Janet Payne
Alliance Blue Cross/Blue Shield

Nancy Pope
Nestlé USA

Diane Ritter
GOAL/QPC

Michael Schneider
Lucent Technologies

Steve Schneider
Rhone-Poulenc
North American Chemicals

W. Charles Slaven
CINCOM Systems Inc.

Larry Smith
Ford Motor Company

Frank Tenne

Paul Tremel
HDR Engineering

Melba Watts
AT&T

Peter Whiting
Rank Xerox Ltd. UK

How to Use this Book

This pocket guide provides a variety of examples, visual cues, design features, and clear, friendly language that we hope will encourage project teams everywhere to use this book, and use it often! Everyone on a project team can use this book as a daily reference on the job and/or as a supplement to training. Have fun!

To Find a Topic

Use the contents page at the front of the book, or the chart at the beginning of every chapter (shown below).

When you need to . . .	Do this activity	Page #

To Find the Start of Each Chapter

Look for the blue box at the bottom of the page.

To See at a Glance What Activities Must be Done for Your Project

First determine the type of project you have. (See page 7 for the distinctions between projects.) Next, look for the key icons that match your project type. Skip the activities that don't show the correct key icon for your project.

1 2 3 ALL project types

2 3 ONLY project types 2 & 3

3 ONLY project type 3

To Find Tips & Pitfalls

Look for this icon: ✋

To Find Each Piece of the Case Study that is Illustrated Through the Book

Look for the flipchart pad or other graphics that have a graph paper fill in them.

Contents

Know the Geography

Plan the Journey

Leadership Summary

Why do organizations need project management?

Project management:

- ensures that customer requirements are met.
- eliminates "reinventing the wheel" by standardizing routine project work.
- reduces the number of tasks that could be overlooked during the project.
- eliminates duplication of effort.
- ensures that projects are in control.
- maximizes the use of resources.

What is involved in the project management process?

- A decision is made to launch a project.
- A charter is prepared, which outlines the requirements and limitations of the project. The charter is usually written by the sponsor in collaboration with either the project leader or the management steering group.
- The charter is discussed with the project team and distributed to management and key project stakeholders.
- The project plan is drafted by the project team, approved by the sponsor, and distributed to management and key stakeholders.
- The plan is executed and monitored, and the final deliverables, i.e., a product, service, process, or plan, are delivered to the project customers.
- The project is evaluated and a close-out report is written and distributed to management and key stakeholders.

Who Has Project Accountability?

Person or group	Is accountable for:
Senior Management	• Ensuring that the organization has a project management process that project teams can follow. • Providing the resources to support selected projects.
Functional Manager	• Providing resources from his or her area to support the project. • Supporting the project objectives.
Sponsor	• Ensuring that the project has clear direction and support. • Providing a charter to the project team. • Ensuring that the project plan meets both the customers' needs and the organization's needs.
Team Leader	• Ensuring that the project satisfies both the customer and the organization. • Ensuring that the project is completed on time and within the project's limits and constraints.
Team Member	• Ensuring that his or her part of the project work satisfies the needs of the project and is completed on time and within budget.

Chapter 1

Creating Successful Projects

Know the Geography

Whether you've been on a hundred journeys with project teams or you're a first time traveler, you and your team need a common understanding of what the terrain will look like when you get involved in projects and project management. This understanding will help your team stay on the most direct route to your destination.

What is a project?

A project is any temporary, organized effort that creates a unique product, service, process, or plan. It can be as simple as the plan for an off-site retreat or as complex as the construction of a medical center, with a team size ranging from a few people to hundreds or even thousands who are working in one location or across continents.

Projects bring together people from a range of jobs and provide them with the opportunity to collaborate in a unique way. Because projects are so diverse and flexible, organizations have increasingly used them as the preferred way to fulfill the needs of their customers.

What is a successful project?

All project teams can judge the success of their projects in the same way:

- The customer is satisfied or delighted with the final deliverable (a product, service, process, or plan).
- The deliverable is given to the customer on time.
- The project team has stayed within the budget and staffing allocations.
- Team members have increased their skills and knowledge as a result of the project.
- The organization has benefited from the lessons learned by the team.

What is project management?

Many project teams work without any guidance on how to create a realistic and useful project plan—OR how to monitor project progress—OR how to respond to requests for changes in the plan. Project management supplies project teams with a process that helps them coordinate their efforts so they may create the right product (or service, process or plan), at the right time, for the right customer, within the resource limits established by the organization.

Project management was once the exclusive job of project managers who most often coordinated the activities of specialized, complex, large-scale projects. In more recent years, however, the role for project managers and project management has been changing. The applicability of project management has widened to include projects of a broad range, from simple to very complex, and from manufacturing to service and education and a host of other areas. Based on the success of the project management approach, the people who lead and work on projects today are not necessarily trained project managers, and have a range of backgrounds and experiences.

While project managers still have an important role to play, all the members of a project team are expected to understand, participate in, and carry out a project by performing project management activities. This book is intended to support this new role for project teams.

How does project management help project teams?

There are many advantages to using project management. These advantages may be better illustrated by listing the pitfalls of NOT USING project management. Here are some of the typical problems that project teams experience when they DO NOT USE a project management process:

- Excessive work loads for some individuals
- Cost overruns
- Team members lack the right skills or expertise for the project
- Staffing conflicts with other projects or assignments
- Relationships among team members are strained
- The scope of the project keeps changing
- Work is redone or duplicated
- Resources are insufficient
- Deadlines are missed

Your project team doesn't have to get trapped in these pitfalls! This Memory Jogger™ describes a simple, easy-to-use process for managing projects that all project teams can use to avoid typical problems and pitfalls, and that will help them to create successful project outcomes every time.

Plan the Journey

Before you start the journey, take some time to review the key terms that you will encounter along the way. The terms that are critical to your understanding of the key concepts in this book are explained in the legend below.

A Legend of Key Terms

Key Term	Definition
Deliverables	Products, services, processes, or plans that are created as a result of doing a project. **A final deliverable** is delivered to the customers of the project. An **interim deliverable** is produced during the process of creating the final deliverable.
Project Scope	A description of the project that includes information on what deliverables will be created and what criteria customers will use to judge whether or not the deliverables meet their needs and requirements.
Resources	Time, effort, and money. Time is monitored with a project schedule, effort is measured in staff time, and money is allocated with a project budget.
Risks	The potential for problems to occur in the process of creating the final deliverable.
Sponsor	The person who acts as liaison between management and the project team, and the person who is responsible for creating the project charter.
Subproject	A smaller project within the main project. A subproject team is formed when a subproject requires more than one person to do the subproject work.

Who will be making the journey?

The beginning of the project management journey is led by the project sponsor. It is the sponsor's job to initiate the project and to create a project charter. When the charter is complete, the sponsor passes the baton, and the project team takes the lead. The key responsibilities of the sponsor and the project team are outlined in the table below.

Key Project Players and What They Do

Project Players	Project Phases			
	Create Charter	Create Plan	Execute & Modify Plan	Complete Close-out
Sponsor	◉	★	△	★
Team Leader	○	◉	◉	◉
Team Members	△	○	○	○

◉ =Accountable for successful completion
△ =Needs to be kept informed
○ = Should collaborate
★ = Approval is required

Project Sponsor

The sponsor is a liaison between management and the project team. His or her role is to initiate the project by creating a *project charter* (Chapter 2). The charter forms the foundation of the team's planning process. If the sponsor does not complete the charter, then the project team must create it and get it approved by the sponsor.

In addition, the project sponsor:

- Ensures that the project is consistent with organizational objectives
- Helps the team overcome obstacles encountered during the project

Project Team

After the project charter has been created and approved, the team is formed and meets for the first time to agree on the ground rules and meeting guidelines that team members will follow throughout the project (Chapter 3). The next step is for the team to develop a *project plan* (Chapter 4), then to execute the plan (Chapter 5), and as a last step, to close out the project (Chapter 6).

There are two key types of roles for the members of any project team:

Project Leader/Manager

- Facilitates the team process
- Collaborates with the team to create and execute the project plan
- Acts as the liaison between the sponsor and the customer
- Monitors the progress of the project

Team Member

- Ensures that his or her part of the project work gets completed on time
- Acts as a liaison with his or her supervisor
- Communicates back to the team on issues
- Monitors the progress of the subproject

Which route will the team take?

Some projects are small and focused, which require very little formal planning activity. Other projects are large and complex, which require considerable coordination between the different groups involved in the project. These large projects require more extensive project plans.

If your team isn't sure which planning activities will best fit the project, use the table below as a tool for planning your project route. Review the characteristics of each project type, then choose the one that best fits your project. Notice that each project type has a corresponding key icon. In Chapters 2 through 6, look for the key icon that is appropriate for your project. If your key icon is on the page, it's an activity your team should do. If you don't see your key icon, your team can skip that activity and go to the next appropriate activity.

Identify your project type

Project characteristics	Project Type		
	Type 1	Type 2	Type 3
When is the work done?	Mostly during team meetings	Outside team meetings	Outside team meetings
Who does the work?	Project team members	Project team members	Subproject team members
Typical examples	• Process/quality improvement projects • Reengineering projects	• Small scale, new product or process development and installation	• Large scale, new product or process development and installation

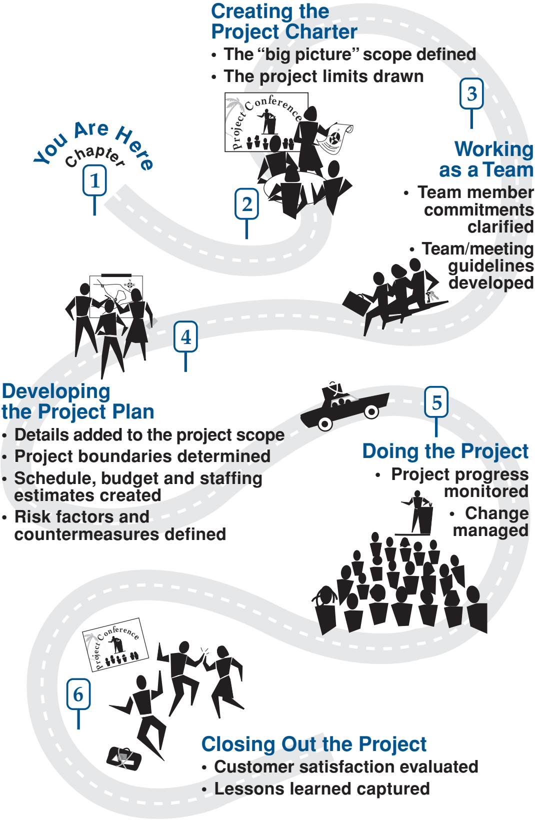
If you're not sure which generic type fits your project, assume you have a type 3 project, but skip the specific activities that don't apply to your project. To help you decide which activities to do or to skip, we've included a matrix of "Recommended Activities for the Project Types" on page 166 and provided descriptions of the activities in the chart at the beginning of every chapter. Review the matrix or the chart to see which activities are recommended for your project type.

What are the important landmarks for your team's journey?

The sequence of MAJOR tasks that a team must complete, from the chartering of the project through close out, is essentially the same for every project—whether the project is simple or complex, or involves a few people or many people. However, projects can take various paths within each of these major tasks based on the scale or complexity of the project. What's important is to do no more and no less than is required by the project management process, depending on what YOUR project requires.

The roadmap on the next page charts the course of any project. The signposts point you to the details of each chapter so that you and your team can move efficiently toward your final destination: a successful project!

A Project Roadmap



Creating the Project Charter

- The "big picture" scope defined
- The project limits drawn

Working as a Team

- Team member commitments clarified
- Team/meeting guidelines developed

Developing the Project Plan

- Details added to the project scope
- Project boundaries determined
- Schedule, budget and staffing estimates created
- Risk factors and countermeasures defined

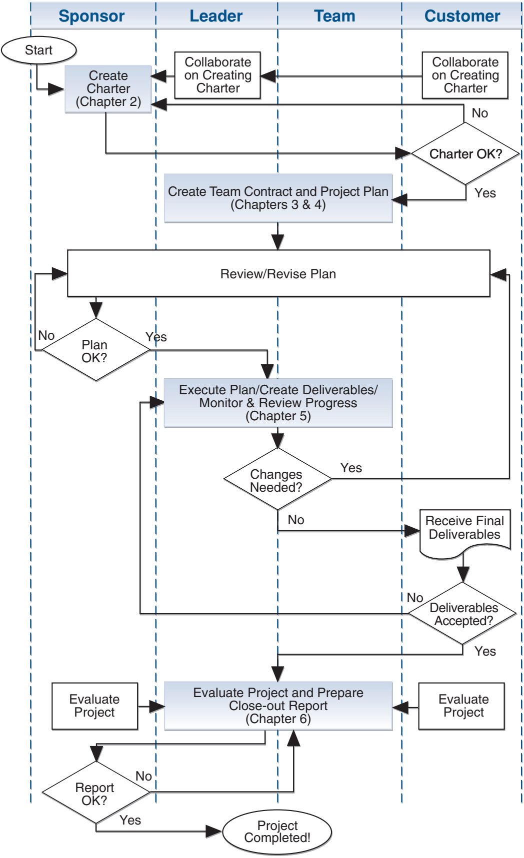
Doing the Project

- Project progress monitored
- Change managed

Closing Out the Project

- Customer satisfaction evaluated
- Lessons learned captured

Project Management at a Glance



Chapter 2

How to Create a Project Charter

The charter is a document that conveys the purpose and requirements of the project to the project team—the "who," "what," and "why" of the project. The chart below shows the basic parts of a charter. A key term to know is "deliverable." A deliverable can be a product, service, process, or plan; for example, a design package, a sales meeting, a plan for a process redesign, or a product prototype. Anything produced for the customers of the project is a "final deliverable." Anything produced along the way is an "interim deliverable."

It is the responsibility of the sponsor to create the project charter. If the sponsor does not create a charter, the project leader, in conjunction with the team, must create it and have it approved by the sponsor.

When you need to:	Do this activity:	Page
Define what the customer expects from the project.	Write an Overview of the Project Scope	13
Define where the project starts and ends.	Determine the Team's Boundaries for Creating the Deliverables	18
Establish what factors are critical to satisfying the customers of the project.	Define the Customers' Criteria for Acceptance	21
Decide who must be involved in the review and approval process.	Determine the Required Reviews & Approvals	22

Continued on next page

When you need to:	Do this activity:	Page
Identify the degree of risk the organization will accept in doing the project.	Establish Risk Limits	24
Identify who must be on the team for the project to succeed.	Select the Project Leader & Team Members	26
Set a date for when the final deliverables will be given to customers.	Set Deadlines for Delivery of the Final Deliverables	28
Limit the amount of money or time that can be devoted to the project.	Set Limits on Staffing & Spending	30
Identify the reports that are needed to monitor and communicate the progress of the project.	Create a List of Required Reports	32
Include constraints and clarify the priorities within the project.	Identify Organizational Constraints & Project Priorities	34
Assemble the charter and distribute it to key stakeholders.	Assemble the Project Charter	37

ATTENTION:
Every project needs a charter! If the sponsor doesn't provide it, create it and get it approved.

Write an Overview of the Project Scope

Why do it?

To describe the objectives, deliverables, and customers of the project, as well as the customers' expectations for the final deliverables. If team members have a clear understanding of the project scope, they will be better able to satisfy the customer.

How do I do it?

1. **Briefly describe the purpose of the project.**
   - Limit the description to three sentences or less.

2. **Give the project a name.**
   - Choose a name that reflects the purpose or the anticipated final deliverable of the project.

Purpose: To hold a three-day conference in the last week of September for project leaders, sponsors, functional managers, project team members, and others who work on projects.

Project name: 3-Day Conference on Project Management

3. **Identify the customers of the project.**
   - Identify who will use the final deliverables of the project. Who will receive the products, services, processes, or plans that are created as a result of the project? These are the customers of the project.

The **conference attendees are the customers** of the 3-day conference on project management.

4. Define the customers' needs and requirements.

- Determine what problem the customer wants to solve by using a specific final deliverable. (Customer need.)
- Find out if the customer is looking for specific features in the final deliverable, or has defined specifications for the final deliverable. (Customer requirement.)

The sponsor may not know what the needs and requirements of the customer are, so the sponsor may delegate this task to the project team.

Project Scope Overview

Project name: 3-day conference on project management

Customers' needs:

1) Increase knowledge and skill to better manage projects.
2) Make contacts with other people who are practicing project management.

One of the customers' requirements: The sessions should address all levels of project management expertise.

5. **Identify and list the final deliverables of the project.**
   - A final deliverable:
     - Is a product, service, process, or plan.
     - Must satisfy customer needs and requirements.
     - Is delivered to the customers of the project.
   - A project usually has only one or two major final deliverables.

If there are some options in which final deliverable will best satisfy the customers' needs and requirements, instruct the team to determine, with the customer if possible, the final deliverable of choice.

If a project team will be producing a product and a process for delivering the product, the activities that must be completed to produce the product will be different from those for producing the process. The product and process (for delivering the product) are two different final deliverables.

Final deliverable: the 3-day conference on project management

6. **Define any deliverables that must be created for the organization.**

   - Do not include any deliverables that will be created for an outside customer. (This was done in step 5.)
   - A deliverable for the organization is a product, service, process, or plan that is created to meet an organizational need or requirement, not a customer need. These deliverables are byproducts or additional deliverables of the project.
   - A deliverable that is created for the organization and delivered to the sponsor is called an organizational deliverable.

     Example: a report on a new area of technology that a team used in its production of a final deliverable for a customer.

7. **Define any additional organizational goals for the project that are not deliverables.**

   - Some examples of organizational goals that are not deliverables are:
     - To generate a specific amount of savings as a result of a reengineering project.
     - To enter into a new market or technology.
     - To use the project as an opportunity to cross-train team members.

Organizational Deliverables and Goals for the 3-Day Conference

Organizational deliverable: "Project Management Process Evaluation Report"

The team members of the 3-day conference project will use the project management process that the organization has recently adopted and summarize their experience in the report.

Organizational goal: Attract at least 300 paid attendees to the conference.

Determine the Team's Boundaries for Creating the Deliverables

Why do it?

To define the start and end points of the team's involvement in helping to create the product, service, process, or plan, so that the team does no more and no less than is required.

How do I do it?

1. **Determine the stage where project team members will begin their work, and the stage in which their work will end.**
    - The table on page 19 shows that there are five generic stages in the development of any product, service, plan, or process. These stages are called "life-cycle stages."
    - In general, the life-cycle stage where a project ends determines what final deliverable is produced.

> *Life-cycle stage boundaries need to be defined for each final deliverable.*

- The word "boundaries" applies to the starting and ending points for creating each final deliverable.
- The creation of any product, service, process, or plan will move through all of the development stages, from concept to delivery, and eventually to retirement, BUT a single project team may not be responsible for all of the stages. The project team may be responsible for one, some, or all of the stages.
- It is the sponsor's responsiblity to tell team members where their boundary of involvement begins and ends for each final deliverable.

Generic Life-Cycle Stages of Creating a Product, Service, Process, or Plan

Life-Cycle Stage	Stage of Development	Generic Descriptions of Activities
1	Create concept or definition	Define the problem or opportunity that the final deliverable will address. Define the characteristics of the final deliverable.
		GATE
2	Design or plan	Design, plan, and/or document each final deliverable. Review and validate or test the design or plan.
		GATE
3	Test or Install	Test prototype. Pilot and verify the plan and process. Train people. Install equipment and/or build a facility.
		GATE
4	Produce or implement	Fully implement plan. Produce and deliver product to the customer. Provide service to customer. Operate process at production levels.
		GATE
5	Retire	Return resources (people, equipment, and/or materials) to the organization. Dismantle equipment and/or buildings. Dispose, recycle, or reuse materials.

Your organization may already have its own life-cycle stages. If so, use those instead of the generic stages described here.

- At the end of each life-cycle stage is a "gate" or checkpoint. The gate acts as a reminder for team members to stop and make sure they have completed all of the necessary activities before they move on to the next stage.

Also determine the boundaries for any deliverables being created for the organization. For example, the conference team's work on the "Project Management Process Evaluation Report" starts and ends at life-cycle stage 2, "Design or Plan."

In projects that use concurrent engineering, different deliverables may be at different life-cycle stages. For example, the development of the process will usually lag behind the development of a product.

Improvement projects usually begin at life-cycle stage 2. Reengineering or redesign projects begin at life-cycle stage 1.

The team's boundaries for the 3-day conference project begin at life-cycle stage 1 (creating the concept for the conference), and end at life-cycle stage 5 (retiring the conference).

Define the Customers' Criteria for Acceptance

Why do it?

To tell the team what criteria the customer will use for judging the acceptability of the final deliverables. Knowing this helps the team create final deliverables that meet the customers' standards.

How do I do it?

1. **Determine the customers' criteria for accepting the final deliverables.**
    - Ask customers for this criteria, whenever possible.
    - If it isn't feasible to ask customers what criteria are most important to their satisfaction with the final deliverable, make the best possible decision on what the criteria should be.
    - Determine a way to measure the customers' level of satisfaction with the final deliverable.

The sponsor should also define his or her own criteria for accepting each organizational deliverable.

Measure for judging customers' level of satisfaction: Conference attendees will be asked to evaluate, on a scale of 1–5, the conference materials, quality of the sessions, and networking opportunities. An overall rating of at least a 4 means that the conference has met the attendee's criteria and it is a success.

Determine the Required Reviews and Approvals

Why do it?

To identify who is responsible for providing review and approval for the interim and final deliverables. Reviews help the team to detect problems or concerns with the deliverables (interim and final) and to avoid or decrease any rework that results from not discovering potential problems early in the project.

How do I do it?

1. **Make a list of the deliverables (interim and final) that require review or approval.**
   - Identify who will provide the review and approval for each deliverable.
   - Note the reason why the deliverable should be reviewed or approved.
   - Depending on the project, it may be beneficial to also include customers in the review and approval process. **For example:** If the project is to improve an internal information system, the customers (potential users) may want to provide review and probably approval at certain stages in the development of the information system.

It's common for people to want a part in the review and approval process, even if it doesn't add value. Question each review requirement to make sure it will improve the quality of the deliverable. This will save time and effort for the project team

Team members will create their own list of reviews when they create a project plan. The sponsor should concentrate on listing the reviews for management and project customers.

Don't forget to include any reviews and approvals that are needed to produce an organizational deliverable.

Reviews & Approvals Required for the 3-Day Conference

Interim Deliverable	Review	Approval	Reason
Final program	Sponsor	Sponsor	To make sure the final program meets the customers' needs.
Hotel contract	Sponsor	Sponsor	To review bids.
Conference plan	Sponsor	Sponsor	To make sure all the logistics have been worked out.

Note: The customers of the project, the conference attendees, do not review or approve any of the interim deliverables of the project. Input from the customer will be solicited by means of market surveys.

Establish Risk Limits

Why do it?

To define the maximum degree of risk that the team should allow in its production of the final deliverables. These risk limits help the team to develop corrective or preventive measures for the final deliverables that have an unacceptable degree of risk to the organization.

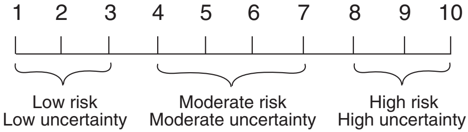
How do I do it?

1. **Assign a limit for the maximum degree of risk that the organization is willing to accept for each final deliverable.**
    - This risk is the uncertainty of not being able to physically produce the final deliverable according to the criteria set by the customer–of not having the ability, skill, or technological knowledge to create the final deliverable as promised. It does not include the risk of not having the needed resources, such as time, people, or money, to create the final deliverable.
    - Using a scale from 1–10, assign a number to represent the risk limit for each final deliverable.

      1 = an extremely low degree of risk or risk-free

      10 = an extremely high degree of risk
    - Where possible, provide an explanation as to which types of risks are acceptable and which are not.

Rating Scale



If the sponsor sets an unnecessarily low risk limit, the team may need to add activities to the schedule and/or money into the budget. The result will be a longer project that costs more money. Set the risk limit at the highest level that is acceptable to the organization.

Also be sure to assign a risk limit to each final deliverable being created for the organization, and a risk limit to each organizational goal. For example, the sponsor for the 3-day conference assigned a risk limit of 1 to the organizational goal of attracting 300 paid attendees to the conference, which is critical to the profitability of the conference, and a risk limit of 2 for the organizational deliverable of creating the "Project Management Process Evaluation Report."

Risk Limits for the 3-Day Conference

The sponsor has assigned the conference a risk limit of 2, and has instructed the team to minimize any risk that the conference will not satisfy the needs and expectations of the attendees.

Select the Project Leader and Team Members

Why do it?

To make sure that the project team includes the right people with the best blend of skills, influence, and knowledge and is led by a capable leader. Choosing the right team makes it easier for the project team to meet its objectives.

How do I do it?

1. **Assign a project leader.**
   - Look for someone who is skilled in these areas:
     - Leadership
     - Facilitation
     - Coordinating tasks
     - Communication
     - Project management knowledge
   - The project leader should be a key stakeholder. A key stakeholder has a strong interest in making the project succeed because he or she (or the area he or she represents) is affected by the activities or deliverables of the project.

Amy Lee is a key stakeholder in the 3-day conference and has proven herself as a successful project leader; she **is the project leader of choice for the 3-day conference.**

2. Select the members of the project team.

- Consider the types of skills, knowledge, and expertise that are important for the project.
- Although all key stakeholders should be considered for membership, they don't necessarily need to have regular membership status (attend all team meetings). Some can be ad hoc members (attend team meetings when their presence is required) and some can be kept informed of the progress of the project through reports and meetings with the team liaison.
- Usually, the smaller the size of the team, the better.

> *Consider including customers and/or a key supplier to maximize customer satisfaction and/or the quality of the final deliverable.*

Selecting the team for the 3-day conference: The conference requires subproject teams, which means it is a type 3 project. Work area representatives have been selected to be on the team and will lead subproject teams within their own work areas.

Project Team	**Work Area**
Jose Ferrara	Facilities
Andy Wellman	Marketing
Ralph Panetta	Print shop
Linda Saunders	Member services
Amy Lee (Project Leader)	New product development

Set Deadlines for Delivery of the Final Deliverables

Why do it?

To set a time limit on when each final deliverable must be given to the customer. It is important to set a deadline at this time because it allows the team to create a schedule that fits within the time boundary for the project.

How do I do it?

1. **Determine when the final deliverables must be delivered to the customer.**
   - The team will build the project schedule around these dates.

Deadline for the final deliverable: The 3-day conference will be held on September 27, 28, and 29. Market surveys that were taken helped to determine that the customer prefers this time of year for attending the conference.

2. **Record any other deadlines that apply to the project.**
   - Are there any other deadlines that must be met, such as deadlines for completing any of the life-cycle stages? For completing the project plan?
   - Record only critical deadlines that, if not met, will have a significant impact on the project.

Avoid giving the team too many additional deadlines. It's the team's job to plan how best to reach the deadlines for the final deliverables.

Don't forget to set deadlines for any organizational deliverables that are required for your project. For example, the sponsor of the 3-day conference wants the "Project Management Process Evaluation Report" issued by December 31.

Additional deadlines for the 3-day conference:
The sponsor wants the conference plan issued by August 1.

Set Limits on Staffing and Spending

Why do it?

To convey the limits on the amount of staff time and the amount of money that the organization will agree to commit to the project. Knowing these limits will help the team to define staffing and spending budgets that are in sync with the amount of money the organization is willing to provide to support the project.

How do I do it?

1. **Define the limit for how much time the staff can devote to the project.**
    - This limit applies to internal staff time only. It does not include outsourcing. Outsourcing is an external cost. See Step 2 on the next page.
    - Staff time can be expressed in hours, weeks, months, or years.
    - Some alternative ways to express staff time may be:
        - "No more than 20% of people's time."
        - "One day every two weeks for three months."
        - "One two-hour meeting once a week."

The 3-day conference has a high priority within the organization, so the sponsor has not put a limit on the amount of staff time that can be devoted to the project. Instead, the sponsor would like the team to estimate the work hours required and then monitor the actual hours invested.

2. **Define the spending limits for the internal and/or external costs that will be expended during the project.**

   - Internal costs = cost for staff time and other internal charges, e.g., supplies, copies, equipment
   - External costs = outside purchases, e.g., contract labor, materials, equipment

Make sure the limits on staff time and spending are realistic; the limits should allow the team adequate resources to create the required final deliverable. Don't expect 100% results with 50% of the needed resources!

If a goal of a project is to produce savings, for example, as a result of a process improvement project, or to produce revenues or profits, this is considered a goal of the organization. See page 16 for clarification of organizational goals.

Spending Limits for the 3-Day Conference

1) There is no limit for internal costs. The sponsor has asked instead that the team estimate the internal costs and then monitor the actual expenses.

2) The spending limit for external costs is $90,000.

Create a List of Required Reports

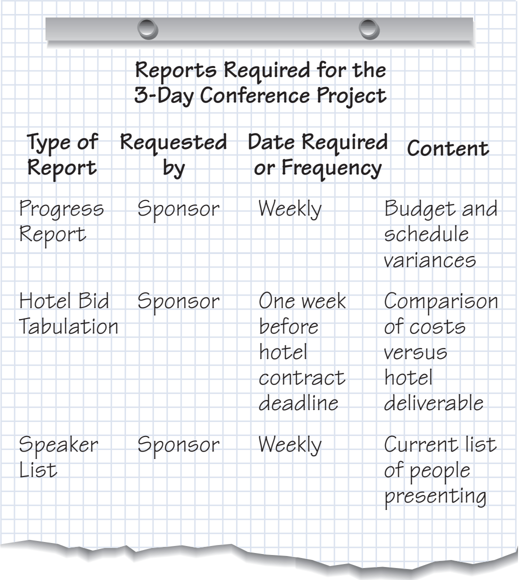
Why do it?

To tell the team what reports are required by management so that the progress of the project can be monitored. These reports help the team to monitor their own progress, provide information to the sponsor and customer, and keep the project on track.

How do I do it?

1. **Create a list of all the reports that are required to monitor the progress of the project.**
   - The team will create a list of reports to help monitor its own progress. The sponsor needs to specify the reports that management needs to monitor the status of the project.
   - On the list, include the following:
     - Type of report
     - Person requesting the report
     - Date required or frequency
     - Content of the report

> *Reports take time and effort to prepare, so ask for only those that are necessary to keep the project on track. Consolidate reports where it's practical to do so.*



Reports Required for the 3-Day Conference Project

Type of Report	Requested by	Date Required or Frequency	Content
Progress Report	Sponsor	Weekly	Budget and schedule variances
Hotel Bid Tabulation	Sponsor	One week before hotel contract deadline	Comparison of costs versus hotel deliverable
Speaker List	Sponsor	Weekly	Current list of people presenting

Identify Organizational Constraints and Project Priorities

Why do it?

To identify any organizational constraints that must be imposed on the project and to assign internal project priorities. Organizational constraints and priorities enable the team to create final deliverables that reflect the special needs of the organization.

How do I do it?

1. **Identify any constraints that the organization will impose on the project.**
   - Constraints are limitations placed on the project such as "No unscheduled equipment downtime," or "No additions to head count."

> *Avoid putting constraints on the project unless they are absolutely essential. Give the team the path of least resistance: the freedom to work creatively in executing the project.*

Constraints on the 3-Day Conference

1) No additional staff can be hired.
2) No capital equipment purchases.
3) Only audiovisual services can be outsourced.

2. **Consider which factor—lower cost, earlier delivery, or more features for the final deliverable—is the highest improvement priority for the project, and which factor is the lowest improvement priority.**
    - **As a baseline, assume the project will meet the deadline, the spending limits, and the customers' minimum criteria for acceptance**. As a way to improve on this baseline, consider which factor—lower cost, earlier delivery, more features—has the highest improvement priority for the project, and which factor has the lowest improvement priority.
    - Give a rank of 1 to the highest priority, a rank of 2 to the next highest priority, and a rank of 3 to the lowest priority.

> *Cost, delivery, and features are interdependent. For example, adding more features will usually increase costs. Earlier delivery can be achieved with more money or fewer features. Project teams often have to make decisions on how to balance these three factors. The sponsor should define the relative priority of these factors so that the team can make decisions on trade-offs during the project that are in line with the*

Improvement Priorities of the 3-Day Conference

"Lower cost" is given the highest improvement priority because the conference is a major profit-generating event for the organization.

"More features" is given the second highest improvement priority because the quality standards for the conference are already high and adding more features will not significantly increase the value of the conference for the participants.

"Earlier delivery" is given the lowest improvement priority because there is no advantage to holding the conference any earlier than the scheduled date.

Priority	**Rank**
Lower cost	1
More features	2
Earlier delivery	3

Assemble the Project Charter

Why do it?

To create a document called the "charter" that details the customers' and the organization's expectations for the project. The charter sets the requirements and the limits for the project and forms the basis for creating a detailed project plan.

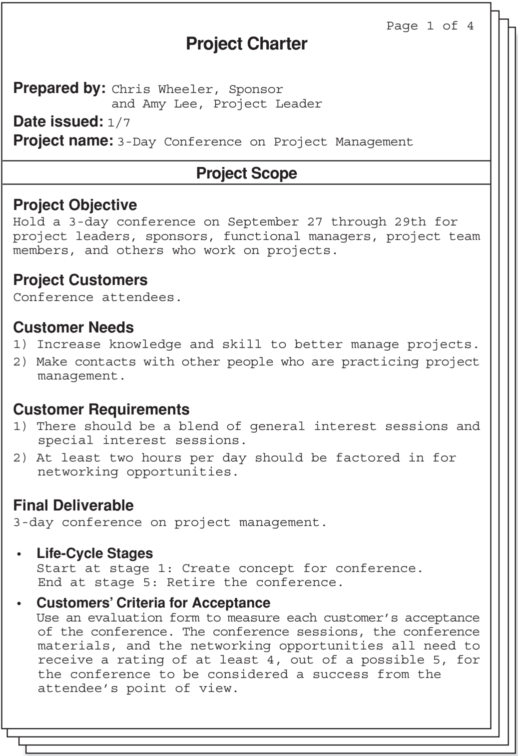
How do I do it?

1. **Assemble the charter using the following four divisions:**
    - **Project Scope:** Describe the scope of the project, including: the project objectives; customer needs and requirements; each final deliverable with its life-cycle boundaries and customer acceptance criteria; each organizational deliverable with its life-cycle boundaries and sponsor acceptance criteria; any organizational goals for the project; and the reviews and approvals required for the project.
    - **Project Scope Risk:** List the risk limit for each *final deliverable* for the project, and the reason for the limit. Also list the risk limit for each *organizational deliverable*, and the reason for the limit.
    - **Project Resources:** Define the resource limitations (deadlines, staffing limits, cost limits) and priorities of the project. List the team assignments.
    - **Project Status Reports:** List the reports that will be required by management to monitor the status of the project.

Include any information in the charter that could be useful to project team members in their efforts to create an effective project plan. The more direction that team members have up front, the less time it will take them to complete a project plan that is in line with the needs and expectations of the organization and project customers.

2. **If required, get the charter approved.**
   - The sponsor may need to have the customer and/or the project steering group approve the charter.
   - If the project team completed the charter, the project leader will need to review it with the sponsor, make whatever modifications might be needed, and then have the sponsor approve it.

3. **Issue the charter.**
   - Distribute copies of the charter to:
     - Project sponsor
     - All members of the project team (both regular and ad hoc)
     - Functional managers who will be affected by the project
     - The customer, where appropriate
     - The project steering group or project office
     - Anyone else who has a stake in the project



Page 1 of 4

Project Charter

Prepared by: Chris Wheeler, Sponsor
and Amy Lee, Project Leader

Date issued: 1/7

Project name: 3-Day Conference on Project Management

Project Scope

Project Objective

Hold a 3-day conference on September 27 through 29th for project leaders, sponsors, functional managers, project team members, and others who work on projects.

Project Customers

Conference attendees.

Customer Needs

1) Increase knowledge and skill to better manage projects.
2) Make contacts with other people who are practicing project management.

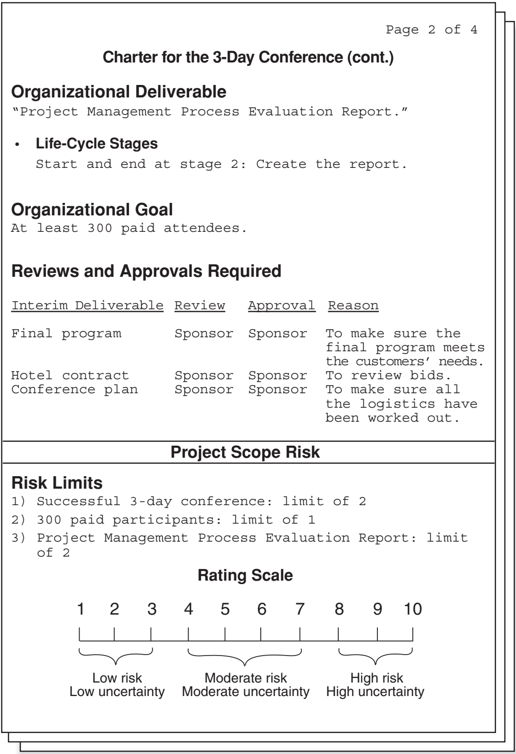
Customer Requirements

1) There should be a blend of general interest sessions and special interest sessions.
2) At least two hours per day should be factored in for networking opportunities.

Final Deliverable

3-day conference on project management.

- **Life-Cycle Stages**
  Start at stage 1: Create concept for conference.
  End at stage 5: Retire the conference.
- **Customers' Criteria for Acceptance**
  Use an evaluation form to measure each customer's acceptance of the conference. The conference sessions, the conference materials, and the networking opportunities all need to receive a rating of at least 4, out of a possible 5, for the conference to be considered a success from the attendee's point of view.



Page 2 of 4

Charter for the 3-Day Conference (cont.)

Organizational Deliverable

"Project Management Process Evaluation Report."

- **Life-Cycle Stages**

  Start and end at stage 2: Create the report.

Organizational Goal

At least 300 paid attendees.

Reviews and Approvals Required

Interim Deliverable	Review	Approval	Reason
Final program	Sponsor	Sponsor	To make sure the final program meets the customers' needs.
Hotel contract	Sponsor	Sponsor	To review bids.
Conference plan	Sponsor	Sponsor	To make sure all the logistics have been worked out.

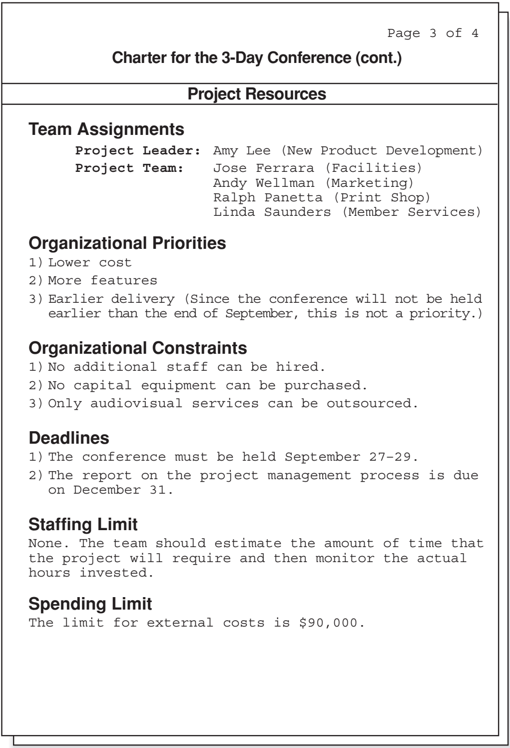
Project Scope Risk

Risk Limits

1) Successful 3-day conference: limit of 2
2) 300 paid participants: limit of 1
3) Project Management Process Evaluation Report: limit of 2

Rating Scale

Note: The rating scale in the example above is not normally included in the project charter. It is shown here only to illustrate to readers the level of risk that is associated with each number.



Page 3 of 4

Charter for the 3-Day Conference (cont.)

Project Resources

Team Assignments

Project Leader: Amy Lee (New Product Development)
Project Team: Jose Ferrara (Facilities)
Andy Wellman (Marketing)
Ralph Panetta (Print Shop)
Linda Saunders (Member Services)

Organizational Priorities

1) Lower cost
2) More features
3) Earlier delivery (Since the conference will not be held earlier than the end of September, this is not a priority.)

Organizational Constraints

1) No additional staff can be hired.
2) No capital equipment can be purchased.
3) Only audiovisual services can be outsourced.

Deadlines

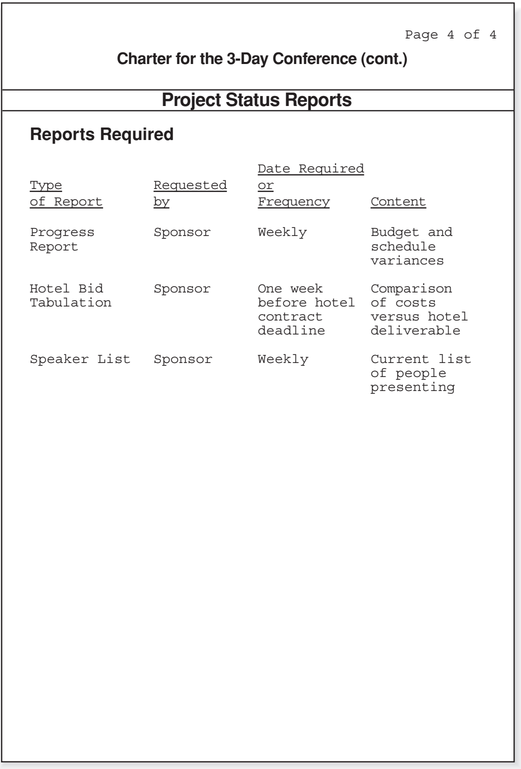
1) The conference must be held September 27–29.
2) The report on the project management process is due on December 31.

Staffing Limit

None. The team should estimate the amount of time that the project will require and then monitor the actual hours invested.

Spending Limit

The limit for external costs is $90,000.



Page 4 of 4

Charter for the 3-Day Conference (cont.)

Project Status Reports

Reports Required

Type of Report	Requested by	Date Required or Frequency	Content
Progress Report	Sponsor	Weekly	Budget and schedule variances
Hotel Bid Tabulation	Sponsor	One week before hotel contract deadline	Comparison of costs versus hotel deliverable
Speaker List	Sponsor	Weekly	Current list of people presenting

Chapter 3

How to Work Together as a Team

At the first meeting, team members need to agree on a basic set of guiding principles or ground rules for running meetings, participating on the project team, and resolving conflicts.

The team also needs a way to capture ideas and issues mentioned during a meeting that cannot be dealt with immediately. (Ideas belong in the "parking lot," and issues, i.e., items that require an action, belong on the issues list.)

Every project team should complete all of the activities in this chapter.

When you need to:	Do this activity:	Page
Clarify the commitments that each team member is making to the project.	Commit to the Project	44
Define the rules for the team process.	Develop Team Ground Rules	45
Decide how meetings will be managed, conducted, and structured.	Determine Meeting Guidelines	47
Record ideas for future discussion.	Create a "Parking Lot"	49
Record issues, i.e., action items, that need to be resolved.	Create an Issues List	50

Commit to the Project

Why do it?

To get agreement within the team on the level of commitment that each team member will be making to the project.

How do I do it?

1. **Discuss the commitments listed below. Add to, remove, or modify the items as appropriate for your team and the project.**
    - Only commit to do work that we are qualified and capable of doing.
    - Be honest and realistic in reporting the progress of the project.
    - Be proactive.
    - Notify the customer(s) and/or the sponsor of any change to the project plan that may affect them.
    - Follow through on our individual commitments to the team and accept responsibility for our actions.
    - Keep other members informed of any potential problems that may affect the team's performance.
    - Focus on what is best for the project as a whole.
    - See the project through to successful completion.

After everyone has agreed to the list of commitments, each team member should sign the list, indicating that he or she agrees to live by these commitments.

Develop Team Ground Rules

Why do it?

To establish ground rules that will help team members recognize and use appropriate behavior, which will result in meetings that are more productive, open, and ultimately more fun.

How do I do it?

1. **Establish ground rules for team behavior.**
    - Consider meeting discussions confidential unless indicated otherwise.
    - Listen openly to other people's points of view.
    - Encourage a divergence of opinions on all topics.
    - Allow everyone the opportunity for equal participation.
    - Help keep discussions on track.
    - Avoid placing blame on someone when things go wrong. Instead, review the process and discuss how it could be improved.

It's often helpful for the team to post the list of ground rules at each meeting.

2. **Agree on how team members will give and receive feedback.**

    When you are giving someone feedback:

    - Give constructive feedback.
    - Don't judge or label the other person; describe a specific behavior or incident.

When you are receiving feedback:

- Listen carefully to the other person.
- Try to understand the other person's point of view.

For more information on feedback, consult The Team Memory Jogger™, *pages 21–27. For a brief summary of team guidelines, refer to* The Memory Jogger™ II, *pages 150–155.*

3. **Adopt a set of guidelines and techniques that will help the team move smoothly through the problem-solving process.**

For brainstorming sessions:

- Encourage everyone to participate.
- Never criticize ideas.
- Think of ideas that are unusual or creative.
- Come up with as many ideas as possible in the time allowed.
- Build on other team members' ideas.

For problem solving and planning:

- Always use data (to the degree possible) or consensus, where necessary.

Refer to The Memory Jogger™ II *to find easy-to-follow instructions for using both data-based tools, (e.g., Pareto, Histogram), and consensus-based tools, (e.g., Affinity, Tree).*

Determine Meeting Guidelines

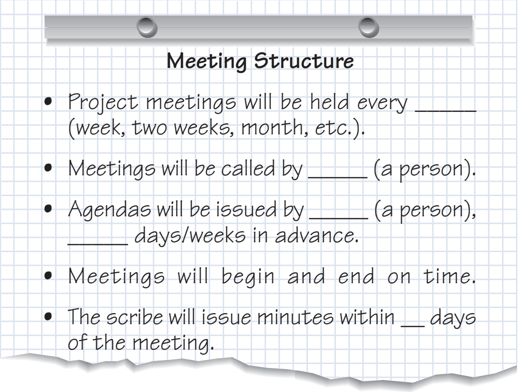
Why do it?

To agree on how team meetings will be structured and what procedures the team will use to keep meetings on track.

How do I do it?

1. **Agree on the basic structure for team meetings.**

   Add to or modify the items listed below, according to team member suggestions.



Meeting Structure

- Project meetings will be held every ______ (week, two weeks, month, etc.).
- Meetings will be called by ______ (a person).
- Agendas will be issued by ______ (a person), ______ days/weeks in advance.
- Meetings will begin and end on time.
- The scribe will issue minutes within __ days of the meeting.

Meeting Procedures

- Ask the project leader to facilitate team meetings.
- Follow the agenda.
- Add unresolved issues to the issues list at every team meeting. For each issue, assign someone to resolve it and set a target date for completion.

- Make sure that any team member who cannot attend the meeting sends a representative in his or her place. The representative should be well prepared and have some authority to make decisions.
- Rotate meeting tasks. (These tasks include taking meeting notes, making room reservations, setting up the room, etc.)
- Propose topics or items to include on the agenda for the next meeting.
- Evaluate each team meeting. *Did we meet our objectives? Did we follow our own guidelines? Did we follow the agenda?*
- Use data- and consensus-based, decision-making tools in team meetings.

Force Field Analysis is a helpful tool in eliciting feedback from the team at the end of a meeting. (See pages 63–65 in The Memory Jogger™ II.*)*

Record the team's ideas on flipchart paper so that the whole team can view the ideas together. (Or tape a piece of banner paper to the wall.) If someone has a misunderstanding, it's easy enough to refer back to the notes on the flipchart paper.

Create a “Parking Lot”

Why do it?

To capture ideas that don’t fit the task at hand but are important to save for future review.

How do I do it?

1. **Write ideas on Post-it™ Notes and place them on flipchart paper.**

   The flipchart paper becomes a common storage area for ideas, as a parking lot is a common storage area for cars. Because of this similarity, this collection of ideas is called a “parking lot.”

> *Recording ideas that aren’t immediately relevant allows the team to move ahead and not worry about losing ideas that may be important to pursue at another time.*

Create an Issues List

Why do it?

To provide the team with a way to capture issues, i.e., items for action, as they arise, so they can be managed and resolved as the project moves forward.

How do I do it?

1. **Create a form for recording the issues.**
   - Design the form to include:
     - a number for each issue
     - a description of the issue
     - who wants the issue resolved
     - the person or group who is responsible for resolving the issue
     - the date by which it should be resolved
     - the date it is resolved
     - how the issue was ultimately resolved

> *If it's unclear whether someone's point belongs on the issues list, write it on a Post-it™ Note, save it in the "parking lot," and review it later to decide if it's really an action item.*

2. **Review current issues at team meetings.**
   - Include a review of current issues on the agenda for each meeting.
   - Resolve key issues before assembling the project plan.
   - When an issue is resolved, use the issues list form to record the date and to describe how it was resolved.

> *The project leader is responsible for keeping a record of all the resolved and unresolved issues.*

Chapter 4

How to Create a Project Plan

A project plan is written by the project team and approved by the sponsor. It describes what the team plans to produce (the interim and final deliverables) and what resources are needed to produce it. Creating a good project plan makes it is easier for the team to successfully execute the project.

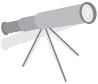
The overview chart on the next page shows nine broad categories of activities that are typically needed to create a project plan. The activities for each category are listed in charts that are similar to the overview on the next page. Use the overview chart to locate these activity charts, then flip to the page you need.

The specific activities that your team will need to work on depends on whether your project is type 1, 2 or 3. If your project is type 1 or 2, just some of the activities will need to be completed. If your project is type 3, your team will need to complete all of the planning activities. To best determine whether or not your team needs to do an activity, use these three methods: review the "When you need to" columns in the charts and the "Why do it?" statements for each activity, and look for the key icon that represents your project. Check these landmarks and your team will have a smoother journey!

Before proceeding, determine your project type (see page 7).

Use the **Legend of Key Terms** on page 4 if you encounter an unfamiliar term. "Organizational deliverable" is defined on pages 16 and 55.

When you need to:	Check the activities in this category:	Page
Specify what interim and final deliverables will be produced.	Define the Project Scope	53
Decide what deliverables will need review and approval and who should be involved.	Complete the List of Required Reviews & Approvals	69
Determine if there are potential problems related to creating any of the deliverables.	Assess the Risks Connected with the Project Scope	73
Identify all the reports needed to monitor the project progress.	Complete the List of Required Project Status Reports	78
Ask whether the right people have been included on the team.	Review Team Membership	82
Develop schedules for completing the project.	Create a Project Schedule	88
Estimate how much staff time will be needed to do the project.	Estimate the Staff Effort Required	112
Estimate how much money will be required to do the project.	Create a Project Budget	121
Assemble the project book and get the plan approved.	Assemble the Project Plan	130



Define the Project Scope

The purpose of a project is to produce a unique product, service, process, or plan (a final deliverable) that will satisfy a customer or a group of customers. The project scope defines who the customers are, the final deliverables that will be produced for them, and the criteria that the customers will use to judge their satisfaction with the deliverables.

When you need to:	Do this activity:	Page
Make sure that everyone understands what will be produced for the customer.	Expand on the Project Scope Description	54
Break down the production of the final deliverables into smaller, more manageable pieces.	Determine What Interim Deliverables Need to Be Produced	56
Know where the team's responsibility for the project begins and where it ends.	Determine What Processes and Projects Fall Within the Project Scope	61
Identify subprojects and work assignments for each team member.	Create a Tree Diagram of Subprojects and Work Assignments	64

Expand on the Project Scope Description

Why do it?

To make sure there is agreement between the project team, sponsor, and customer on what the final deliverables of the project will be.

How do I do it?

1. **Make sure everyone on the team understands the "Overview of the Project Scope" section of the project charter.**
    - This section of the project charter defines the following:
        - purpose of the project
        - name of the project
        - customers of the project
        - customers' needs and requirements
        - the final deliverables of the project
        - the organizational goals and organizational deliverables of the project
    - If the team does not understand the scope of the project as described in the charter, the team should ask the sponsor for clarification before moving on with the project.

2. **Write a description of the final deliverables that will be produced by the project.**
    - The charter identifies the final deliverables of the project, but it may not provide enough detail on the features of the final deliverables. It is the team's job to write a detailed description of the final deliverables so that the sponsor and/or customers have a complete picture of what will be produced.

Record the team's ideas for what the project scope should include on flipchart paper so that the whole team can view the ideas together. In fact, all of the project planning activities should be written down on flipchart or banner paper so that the team can see the elements of the plan as it is created.

3. **Define the customers' criteria for acceptance of the final deliverables.**
   - Review the section in the project charter where the sponsor has broadly defined the customers' criteria for accepting the final deliverables.
   - Is the sponsor's list of criteria complete? If not, add the necessary detail about a specific criterion, and/or add additional criteria to the list.
   - The criteria should describe results that are important to the customer.
   - Where possible, make the criteria measurable.

Don't forget: The team will also need to . . . write a description for . . . define the life-cycle stages for . . . and define the sponsor's criteria for accepting . . . each organizational deliverable that will be produced by the project. (Remember that an organizational deliverable is a product, service, process, or plan that is created to meet an organizational need, not a customer need.)

The team also needs to review any organizational goals for the project that were defined by the sponsor, so that they may be incorporated in the project plan.

See page 16 for further clarification of organizational goals and deliverables.

Determine What Interim Deliverables Need to Be Produced

Why do it?

To describe in detail the things that must be produced by the team, before the final deliverables are completed. These are the building blocks for developing the project milestones, schedule, and budget.

How do I do it?

1. **Define the interim deliverables that will be produced for each final deliverable.**
   - An interim deliverable directly leads to or supports the production of a final or organizational deliverable.
   - The team needs to define all of the interim deliverables that will be produced from the beginning life-cycle stage (for the deliverable) to the ending stage. For example, if a final deliverable starts at life-cycle stage 2 and ends at life-cycle stage 3, the interim deliverables that must be defined are those produced only in stages 2 and 3.
   - Use the generic life-cycle activity descriptions as clues to what interim deliverables are possible for your project. See the table on pages 57–58.
   - If your organization has its own life-cycle stages, use those instead of the generic example.
   - Check the "parking lot" and the issues list for ideas that might be interim deliverables.

> *To come up with the list of interim deliverables, think chronologically. What will be produced first? What should be produced after that? Continue asking this question until the team gets to the final deliverable.*

Life-Cycle Stages and Interim Deliverables for the 3-Day Conference

This table shows the life-cycle stages, activities, and some of the interim deliverables for the 3-day conference. The team deleted the generic activities in the table that did not fit the conference.

Life-Cycle Stage	Stage of Development	Stage Activities	Interim Deliverables for the Conference
1	Create concept or definition	Define the problem or opportunity that the conference will address. Define the characteristics of the conference.	• Preliminary program
2	Design or plan	Plan, and/or document the interim and final deliverables. Review the plan.	• Hotel contract • Speaker contracts • Final program • Conference plan and schedule (set up, workers, layout of facilities, room assignments,registration, tear-down)
3	Test or install	Train people. Install equipment.	• Speaker instructions • Trained conference workers • Equipment set-up
4	Produce or implement	Implement the plan fully. Provide service to customer.	• Conference proceedings • Audiotapes of sessions • Conference

Continued on next page

Life-Cycle Stages Table continued

Life-Cycle Stage	Stage of Development	Stage Activities	Interim Deliverables for the Conference
5	Retire	Return resources (people, equipment, and/or materials) to the organization. Dismantle equipment. Dispose, recycle or reuse materials.	• Equipment break-down • Conference materials returned to stock or recycled

Don't forget about defining the interim deliverables for your project's organizational deliverables as well. (Use the same instructions that are described in Step 1.) For example, one of the organizational deliverables for the 3-day conference team is the "Project Management Process Evaluation Report." Since the team's work on this report begins and ends in life-cycle stage 2, the interim deliverables that need to be defined are those that are related to the activities in stage 2 only. The interim deliverables then are defined as "creating an outline," and "creating the draft report."

2. **Define the quality criteria for each interim deliverable if the interim deliverable could have a significant impact on the quality of a final deliverable.**
   - Monitoring the quality of interim deliverables helps to ensure that each final deliverable will meet the customers' criteria for acceptance.
   - Where possible, make the criteria measurable.

After the final deliverables of a project are delivered to customers, it is too late to do anything about their quality. Quality measures for interim deliverables allow the project team to anticipate and respond to quality issues before the final deliverables go to the customer.

Internal Quality Criteria for the 3-Day Conference

Final Deliverable	**Internal Quality Criteria**
3-Day Conference on Project Management	• A rating of 4 or 5 given by members of a focus group for the topics selected for the conference. • A rating of 4 or 5 for each conference speaker, based on an internal rating system that evaluates prior speaker performance, speaker references, speaker topic, and so on. • At least 90% of all the sessions are included in the conference proceedings. • Quality rating of 4 or 5 on an internal evaluation of speaker materials. • At least 2 hours per day devoted to networking opportunities during the three-day conference.

Don't forget to define the internal quality criteria for the interim deliverables that could have a significant impact on the quality of the organizational deliverables. For the 3-day conference, the team determined that no internal quality criteria were needed for the project's organizational deliverable, i.e., the "Project Management Process Evaluation Report."

Determine What Processes and Projects Fall Within the Project Scope

Why do it?

To identify where the team's responsibilities for the project start and end. Projects tend to intersect and overlap with other activities in the organization. The team needs to know the activities included in the project scope and those that are excluded.

How do I do it?

1. **Identify the processes that are part of the project scope.**
    - A process is a set of steps or activities that allows a person or team to produce the same outcome, with minor variations, every time the process is applied.
    - The project scope is a description of what interim and final deliverables will be produced.
    - Review the project's interim and final deliverables to identify the processes that will produce those deliverables.

3-Day Conference

The processes that are part of the project scope are:

- Contracting and facilities set-up process
- Marketing process
- Graphic design and printing process
- Registration process
- Program development process

Don't forget to review the organizational deliverables of the project so that your team can identify the processes that will produce those deliverables.

2. **Identify any processes that will significantly affect the project or that will be significantly affected by the project.**

   - Do not include processes that are part of the project scope. (Those identified in Step 1.)

The processes that the team identifies as outside the project scope usually provide some inputs into the project, however, the project team is not directly responsible for carrying out these processes.

3-Day Conference

The process that is affected by the 3-day conference, but is not part of the project scope, is the:

- Billing and order-taking process

3. **Identify any projects that will significantly affect the team's project or that will be significantly affected by the team's project.**

   - What other projects, if any, overlap with your team's project? Could their activities or the deliverables they will produce get in the way of your team's project?

- What projects will be affected by your team's project, but are not the responsibility of your team?
- What projects will supply inputs to your team's project?
- Do not include projects that are part of the project scope. (Subprojects for example.)

Be very clear on the breadth and depth of your project team's responsibilities. The team should not get involved in other processes or projects that need improvement, unless the sponsor approves this involvement.

Watch out for other projects that are working on producing a deliverable that could adversely affect your project team's activities. For example, if another team is creating a procedure for using purchasing cards and your team has been asked to redesign the procurement system, their purchasing card (their deliverable) could have a major impact on how you proceed with your project. If this is the case, invite someone from the other team to participate in your project and get direction from the sponsor on how to integrate the two projects.

3-Day Conference

The project that is affected by the 3-day conference, but is not part of the project scope, is:

- Membership drive project

Create a Tree Diagram of Subprojects and Work Assignments

Why do it?

To divide up the work of the project and to assign that work to subprojects. The tree diagram shows at a glance what subprojects will be carried out and which people will be held accountable for making sure the work assignments are done. Subproject members then convert the work assignments into their own project plans.

How do I do it?

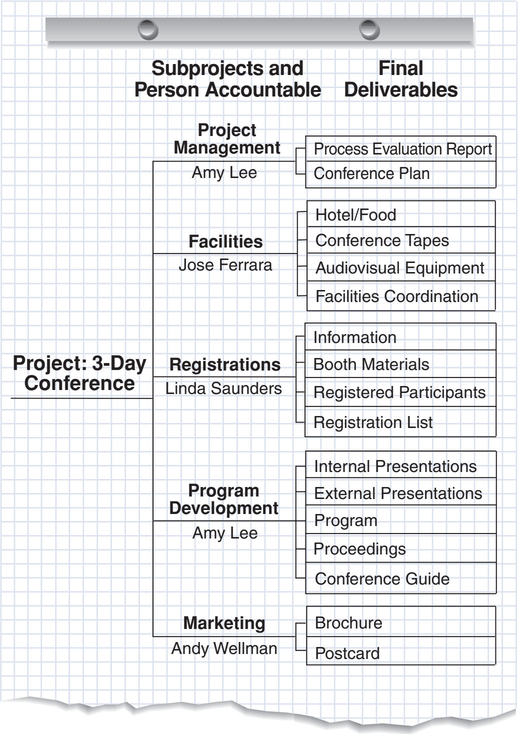
1. **Create a list of subprojects.**

   - A subproject represents a chunk of work that will be overseen by a project team member.
   - Subprojects should be aligned with the way the organization breaks down work (work unit).
   - Processes that are part of the project scope represent natural work breakdowns, so using the list of processes is a good starting point for determining subprojects.
   - If your organization breaks down work by function, geographic location, or by business unit, use these distinctions as starting points for determining subprojects.
   - Subprojects may also include work that falls outside the boundaries of the work unit. The subproject team representative or leader will be responsible for coordinating that work with other work units.

It will probably be important for your project to include a subproject called "Project Management." This subproject will include the reports and deliverables that will be produced by the project as a whole, and any items that don't fit another subproject.

2. Create a tree diagram of subprojects.

- Write the name of the project on the lefthand side of a piece of flipchart paper, positioning it so that you have room to expand the diagram from left to right.
- On the first tier of branches write the names of the subprojects.



3. **Assign a team member to lead or represent each subproject.**
    - The person who is asked to lead or represent a subproject will be accountable for ensuring that the deliverables for that subproject are produced on time and within the limits and constraints determined for the project.
    - Add the name of the person accountable for each subproject on the subproject branch. Only one person can be accountable for each subproject.
    - The project leader will be accountable for the "Project Management" subproject.

If the project is type 3, each person who is accountable for a subproject will need other people to help create the subproject deliverables and will therefore become a subproject team leader. This subproject leader needs to provide the team with a charter, and should work with the subproject team members to create a subproject plan. In a type 2 project, the person who is accountable for the subproject will be doing most of the work solo, and therefore he or she will not be leading a subproject team. For this person to be successful in completing the subproject work, it's a good idea for this subproject representative to create a charter for his or her own subproject work and to review it with the project team.

4. **Define the deliverables that each subproject will produce.**
    - Each subproject leader or representative should identify what deliverables the subproject will produce at the end of the subproject. These are called final subproject deliverables.

- Write the names of the final subproject deliverables on the next branch to the right of each subproject.
- If team members are having trouble defining what final deliverables each subproject will produce, they can brainstorm possible deliverables, placing each one on a Post-it™ Note. The team should ask, "Is this a deliverable that will be produced at the end of the subproject process?" If it is, place the Post-it™ Note next to the appropriate subproject. If it isn't, put it in the "parking lot" for possible use in future steps.

Don't forget to assign each organizational deliverable to a subproject. Most commonly they fall into the "Project Management" subproject.

5. Review the list of interim deliverables for the project and make sure that each one is included in a subproject on the tree diagram.

If an interim deliverable is produced by the project as a whole, place it in the "Project Management" branch. These interim deliverables are usually produced as a result of several subproject activities.

3-Day Conference

The conference plan is an interim project deliverable that does not belong with any of the subprojects. It is a synthesis of the plans created by each subproject. The Post-it™ Note for "conference plan" belongs with the subproject called "Project Management."

6. Review the tree diagram.

- Are there any duplicate deliverables on the branches? If so, decide which subproject is most appropriate and remove the duplicates. If the same deliverable appears in more than one subproject, the team needs to determine who is really accountable for producing the deliverable. Determine which duplicate to keep by asking, “Who is the best person to ensure that this deliverable gets produced?” and then eliminate the others from the tree diagram.
- Have any deliverables been overlooked? If so, add them to the appropriate subproject.

3-Day Conference

The graphic design and printing process is one of the five processes that are part of the conference scope.

Initially, when the team was writing down the names of subprojects, the graphic design and printing process was included as a subproject. Then the team wrote down the final subproject deliverables: the postcard, brochure, final conference program, and conference proceedings.

The team quickly realized, however, that the final deliverables for the graphic design and printing department were also listed, more appropriately, under the subprojects called “Marketing” and “Program Development.” Therefore, the team eliminated “Graphic Design and Printing” as a subproject.

Complete the List of Required Reviews & Approvals

Most deliverables, either interim or final, have to be reviewed and/or approved before they can be delivered to the customer. Defining what reviews and approvals should be integrated into the project process allows the team to schedule and coordinate the review activities.

When you need to:	Do this activity:	Page
Expand on the review and approval list supplied in the charter.	Complete the List of Reviews and Approvals	70

Complete the List of Reviews and Approvals

Why do it?

To complete the initial list of reviews and approvals that was included in the project charter. The team may find in reviewing the charter that there are additional people on the team or in the organization who should be included in the review and approval process. By completing this list, the team can include these activities in the project schedule and thus make sure that they are coordinated and completed on time.

How do I do it?

1. **Create a table that shows what reviews and approvals are needed for the project.**
    - Include:
        - – the name of the deliverable that needs to be reviewed
        - – the person who will ensure that the deliverable gets produced
        - – the purpose of the review
        - – the names of those people who will provide review or approval
        - – a column for the date the review or approval must start and the date by which it must be completed

> *Sponsor and customer reviews can be politically useful for building and maintaining support for the project. They reduce risk and keep the sponsor and customer informed of the team's progress.*

Don't forget to include reviews and approvals for any organizational deliverables of the project. Also include any interim organizational deliverables that might require review or approval.

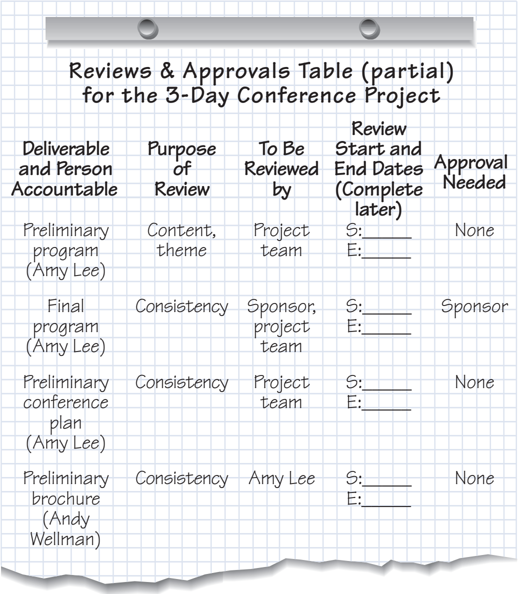
2. **Fill in the table with the relevant information from the project charter.**
   - This information can be found in the "Required Reviews and Approvals" section of the project charter.

If people outside the team need to participate in reviews, publish the table early enough so they can plan the reviews into their schedules.

3. **Determine if additional reviews and approvals are required.**
   - Additional reviews and approvals can include team members, departmental managers, other outside stakeholders, etc.
   - Add the appropriate information to the table: what will be reviewed or approved, and who will do it.

Try to keep the number of reviews to a minimum. Question each review requirement to make sure that it will add to the quality of the deliverable.

The 3-day conference team identified some reviews that were needed in addition to those listed in the charter.



Reviews & Approvals Table (partial) for the 3-Day Conference Project

Deliverable and Person Accountable	Purpose of Review	To Be Reviewed by	Review Start and End Dates (Complete later)	Approval Needed
Preliminary program (Amy Lee)	Content, theme	Project team	S:______ E:______	None
Final program (Amy Lee)	Consistency	Sponsor, project team	S:______ E:______	Sponsor
Preliminary conference plan (Amy Lee)	Consistency	Project team	S:______ E:______	None
Preliminary brochure (Andy Wellman)	Consistency	Amy Lee	S:______ E:______	None

4. **After the project schedule has been completed, add in the dates for when each review should start and end.**

   - The schedule of project activities includes the start and end dates for each activity that must be done for the project. This type of schedule is explained more fully on pages 102–109 in the section called "Create a Project Schedule."

Assess the Risks Connected with the Project Scope

Any project has some degree of risk associated with the organization's ability to create deliverables that conform to the customer's criteria for acceptance. The risks that are discussed in this section include any obstacles that could prevent the organization from meeting the acceptance criteria. Typical obstacles include an inability to find the right people who have the necessary skills or expertise, and the inability to access the technological know-how that is needed to create the project deliverables. (Obstacles in this case are not limitations related to time, people or money.)

When you need to:	Do this activity:	Page
Reduce the impact of potential obstacles to producing the final deliverables.	Assess the Risk in Producing the Final Deliverables	74

Assess the Risk in Producing the Final Deliverables

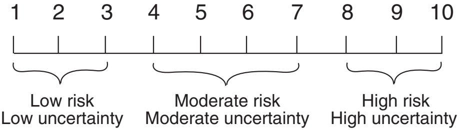
Why do it?

To inform the sponsor, and the customer when appropriate, of the degree of risk connected with the project scope, and the countermeasures that the team has developed, if needed, to bring the risks down to levels that are acceptable to the organization.

How do I do it?

1. **Assign a risk rating to the team's ability to produce each final deliverable. List the reasons and assumptions for the risk rating assigned by the team.**
    - Use a scale from 1–10 to assign the risk rating, with 10 as the highest risk, and 1 as the lowest.
    - A low risk rating (1–3) means there is a low degree of risk or uncertainty involved in producing the final deliverable according to the customer's criteria for acceptance.
    - A moderate risk rating (4–7) means there is a moderate degree of risk or uncertainty involved in producing the final deliverable according to the customer's criteria for acceptance.
    - A high risk rating (8–10) means there is a high degree of risk or uncertainty involved in producing the final deliverable according to the customer's criteria for acceptance.

Rating Scale



The team should assess its capability to produce the final deliverables of the project. In making this assessment, the team does not need to consider whether or not the resources (time, people, money) needed to produce the final deliverables will be available.

2. **Compare the team's risk rating to the limit defined in the charter. For each final deliverable that has a risk rating above the limit, create countermeasures to bring the risk down to the limit.**

    - Brainstorm possible countermeasures that will reduce the risk. One method for identifying risks and countermeasures is to use a PDPC (Process Decision Program Chart). Consult *The Memory Jogger™ II*, pages 160–162, for instructions on how to use this tool.

    - From the brainstormed list of countermeasures, select those that will bring the team's risk rating down to the limit. If a limit was not set by the sponsor, bring the risk rating down to a level that is acceptable to the team or get clarification from the sponsor on what the acceptable level of risk should be for each final deliverable.

    - If the team cannot bring the risk rating down to the limit, this issue should be added to the issues list and the project leader should resolve it with the sponsor.

If there is a way to bring the risk rating down to a level lower than the sponsor's limit—without adding costs such as time, money, or effort—the team should go ahead and do it. However, if additional costs would be involved, the team should put the additional countermeasure(s) on the issues list and then discuss them with the sponsor.

Don't forget to assess the risk for each organizational deliverable and each organizational goal. Compare the team's risk rating to the sponsor's limit. If the risk is above the limit, define countermeasures to reduce the risk.

Team's Risk Rating Versus the Sponsor's Risk Limit for the 3-Day Conference

Deliverable or Goal	Team's Risk Rating	Reason for Risk	Sponsor's Risk Limit
Conference	3	Outstanding speakers are hard to find.	2

Countermeasures Chosen (to bring the risk rating down to the sponsor's limit)

1. Offer to publish selected papers in a monthly magazine.
2. Consider an honorarium for speakers.

3. **Assign a person to be accountable for each countermeasure that is chosen.**
   - The person must be a member of the project team.
   - The person who is assigned to a countermeasure is accountable for making sure it is carried out correctly.

Person Accountable for Countermeasures Chosen for the 3-Day Conference

Final Deliverable	Countermeasures Chosen	Person Accountable
Conference	Offer to publish selected papers in a monthly magazine.	Amy Lee, Program Development
	Consider an honorarium for speakers.	Amy Lee, Program Development

Be attuned to any changes that could affect the risk associated with your project, such as changes in the scope of the project, or changes in the environment, i.e., organizational, regulatory, competitive, and technological changes. If these changes do occur, your team will need to reassess the risk rating and countermeasures that were developed for each deliverable for your project.

Complete the List of Required Project Status Reports

It is important for everyone—all the project team members, the sponsor, and customers—to know how the project is progressing. This is accomplished through progress review meetings and project status reports. (These review meetings are described in Chapter 6, How to Close Out the Project.) Status reports describe the progress the team is making in getting the deliverables produced, in staying on schedule, and in meeting the staff time and spending expectations that are described in the project plan. These status reports will highlight any problems that are occurring, or have the potential to occur, with the production of the deliverables, or in trying to maintain the schedule or the budget.

When you need to:	Do this activity:	Page
Inform stakeholders of the progress being made in creating the deliverables and the expenditure of resources.	Create a Complete List of Project Status Reports	79

Create a Complete List of Project Status Reports

Why do it?

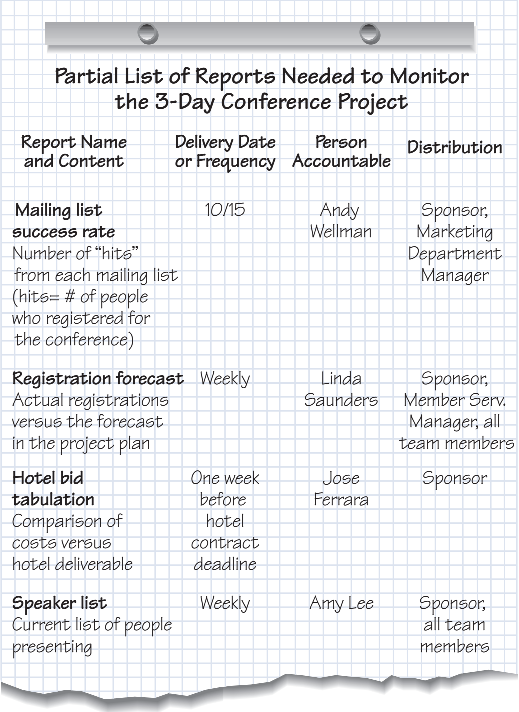
To keep everyone informed on the progress the team is making in producing the project deliverables or in spending the organization's resources. These reports provide an update for the team, the sponsor, and the customer on the current status of the project.

How do I do it?

1. **Create a list of the reports that will be required to monitor the status of interim or final deliverables.**
    - On the list, include the following:
        - Name of the report
        - Person who is accountable for the report
        - Date required or frequency of the report
        - People who should receive the report
        - Content of the report
    - Include reports that were requested in the charter.

The team should make sure that there is enough time built into the schedule to produce these reports.

Also include progress status reports on any of the organizational deliverables and interim organizational deliverables for your project, if they are needed.



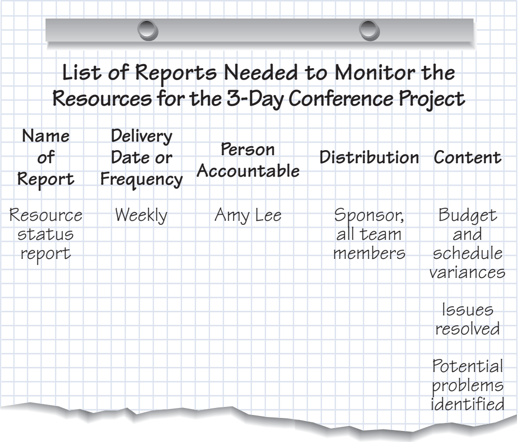
Partial List of Reports Needed to Monitor the 3-Day Conference Project

Report Name and Content	Delivery Date or Frequency	Person Accountable	Distribution
Mailing list success rate Number of "hits" from each mailing list (hits= # of people who registered for the conference)	10/15	Andy Wellman	Sponsor, Marketing Department Manager
Registration forecast Actual registrations versus the forecast in the project plan	Weekly	Linda Saunders	Sponsor, Member Serv. Manager, all team members
Hotel bid tabulation Comparison of costs versus hotel deliverable	One week before hotel contract deadline	Jose Ferrara	Sponsor
Speaker list Current list of people presenting	Weekly	Amy Lee	Sponsor, all team members

2. **Create a list of the status reports needed to describe how the resources of the project, (time, staff, money, equipment) are being used.**
   - Include the same information listed in Step 1 (name of report, person accountable, etc.).
   - Include reports that were requested in the charter.

- Usually the content of a status report compares the estimated to the actual, that is, the difference between the team's expectations, which are described in the project plan, and the actual expenditure of resources.

If the team is planning to have regular team meetings to review the status of the project, then the minutes of these meetings can serve as the project status report.



List of Reports Needed to Monitor the Resources for the 3-Day Conference Project

Name of Report	Delivery Date or Frequency	Person Accountable	Distribution	Content
Resource status report	Weekly	Amy Lee	Sponsor, all team members	Budget and schedule variances Issues resolved Potential problems identified

Review Team Membership

Having the right people on the team can mean the difference between a successful project and a not-so-successful one. The initial composition of the team was assigned as part of the charter. In preparation of the project plan, the team needs to review the composition of the team to make sure each person brings the right skills and expertise to the project, and that they represent the project's stakeholders.

When you need to:	Do this activity:	Page
Ensure that the right people with the right skills and expertise are on the team.	Review and Modify Team Membership	83
Ensure that stakeholders' interests are represented.	Review and Modify Team Membership	83

Review and Modify Team Membership

Why do it?

To create the best possible team, so the right people are involved in the project and that they have the appropriate membership status.

How do I do it?

1. **Review the membership of the team to identify any gaps or overlaps between the assigned team and the skills and expertise required to carry out the project.**
   - If there are gaps or overlaps in skills and expertise, recommend changes in membership that will provide the team with the right mix of skills and expertise.
   - People can participate on the team as either a regular team member who attends all team meetings, or as an ad hoc member. Ad hoc members are required to attend team meetings only when an agenda item requires their presence.

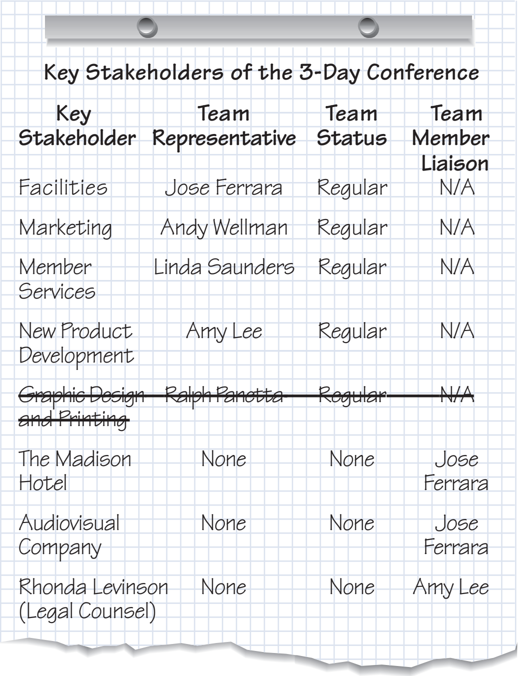
> *Try to limit regular team membership to only the people who need to participate in the entire project. Asking people who do not have a large stake in the project to participate in every meeting is a waste of their time. Remember that other people can be brought into the process at any time without becoming regular or ad hoc members of the project team.*

2. **Identify the key stakeholders that should be represented on the team.**
   - Key stakeholders include departments or functional areas of the organization that will be affected by the project. They also include the customers and key suppliers of the project.

- Key stakeholders can also include subprojects. These stakeholders should be represented by team members who have regular membership status since these team members will represent a subproject or lead a subproject team. (Only type 2 and 3 projects can have stakeholders that include subprojects since type 1 projects don't have subprojects.)
- The team needs to determine what membership status the customer should have, if any.
- Suppliers and special interest groups may also need to be represented on the team. The status can be regular or ad hoc, depending on the anticipated level of involvement of the team member.
- If a key stakeholder doesn't need a team representative, assign a team member to act as a liaison for the stakeholder.

Remember, not all of the project's stakeholders have to be on the team. Consider every group with an interest in the project and then decide what the best composition of the team is. Stakeholders can be kept informed of the progress of the project through progress reports; they don't have to attend team meetings.

Ralph Panetta was originally assigned to be a regular team member, however, the project team decided to include the activities of his department under the "Marketing" and "Program Development" subprojects. Ralph doesn't need to be on the team, so instead, he will serve as an ad hoc member on the two subproject teams.



Key Stakeholders of the 3-Day Conference

Key Stakeholder	Team Representative	Team Status	Team Member Liaison
Facilities	Jose Ferrara	Regular	N/A
Marketing	Andy Wellman	Regular	N/A
Member Services	Linda Saunders	Regular	N/A
New Product Development	Amy Lee	Regular	N/A
~~Graphic Design and Printing~~	~~Ralph Panetta~~	~~Regular~~	~~N/A~~
The Madison Hotel	None	None	Jose Ferrara
Audiovisual Company	None	None	Jose Ferrara
Rhonda Levinson (Legal Counsel)	None	None	Amy Lee

3. **Determine whether other processes or projects should have representation on your team.**
   - Consider only the processes and projects that will significantly affect, or be affected by your project. Include a representative on the team only when he or she will be needed to participate in team meetings.
   - The steps involved in identifying the processes and projects that may significantly affect the team's project (or be affected by it) are discussed on pages 61–63, under "Determine What Processes and Projects Fall Within the Project Scope."
   - If the process or project doesn't require a team representative, assign a team member to act as a liaison.

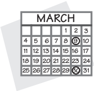
Team members who represent the processes and projects (that affect or are affected by the main project) usually have ad hoc team status.

Other Processes and Projects Affected by the 3-Day Conference

Process or Project	Team Representative	Team Status	Team Member Liaison
Project management process project	None	None	Amy Lee
Billing and order-taking process	Lyle Yendow	Ad hoc	None
Membership drive project	None	None	Amy Lee

4. **Compare the proposed team to the team assigned by the sponsor.**
   - If discrepancies exist, include them as issues on the issues list that the project leader will need to resolve with the sponsor.

5. **Periodically reassess team membership.**
   - If changes are made to the project scope, reassess team membership to determine whether the team is still composed of the right people.



Create a Project Schedule

The value of creating a schedule is to provide team members with a means to coordinate their activities so they may meet their deadlines. A **milestone schedule** allows the team to take the goal of the project, (to create a final deliverable), divide it into major subgoals, and assign deadlines to each subgoal. A **deliverables schedule** is used to show the delivery dates for all of the project deliverables. An **activity schedule** shows the duration and completion date for each project and/or subproject activity. Once an activity schedule is completed, the information can be entered into a project management software program, which will provide the team with a way to update and monitor the schedule as the project progresses. A **Gantt chart** shows the project schedule at a glance, and is useful for both the project team and people outside the project team.

When you need to:	Do this activity:	Page
Set interim goals that will help the team measure its progress toward the final deliverables.	Construct a Milestone Schedule	89
Show the delivery dates for each deliverable and who is accountable for each one.	Create a Deliverables Schedule	94
Determine when each activity will be completed and who will be responsible to carry it out.	Create an Activity Schedule	102
Create a visual overview of the project that shows the major activities of the project and when they will be done.	Draw a Gantt Chart	110

Construct a Milestone Schedule

Why do it?

To establish interim goals and deadlines that will guide the project team's progress toward its ultimate goal. The milestone schedule is the foundation upon which all other project schedules are built. It provides the team with an understanding of the sequence of major accomplishments of the project and when they need to be completed.

How do I do it?

1. **Define the start date for the project and the date that the team expects to close out the project.**
   - To begin constructing the milestone schedule, tape some banner paper to a wall.
   - Draw a horizontal line along the bottom of the paper to represent a timeline that encompasses the entire length of the project.
   - At the beginning of the line, record the date that the project started.
   - A project usually starts when the project leader receives the charter. However, if the project leader doesn't receive a charter from the sponsor, the start date is when the team begins to create a charter of its own.
   - At the end of the line, record the date that the project is expected to be closed out.
   - A project is closed out after the final deliverables have been accepted by the customer, feedback from the customer and sponsor has been received and evaluated, and the results of the project and the team's learnings have been summarized in a close-out report.

- Divide the horizontal line into time periods. Most project timelines will be divided into weeks or months. (Weeks for shorter projects, months for longer ones.)

2. **Record the date for when the team expects the sponsor to accept the project plan.**

3. **Add the deadline dates for each final deliverable at the appropriate points on the timeline.**
   - The deadline dates for the final deliverables should have been provided in the charter. If these dates were not provided, the team will need to decide when they think each deliverable can and should be delivered. These dates are referred to as delivery dates.
   - Deadline dates and delivery dates may not be the same dates. The deadline date is when the customer expects to receive a final deliverable. The delivery date is when the team thinks it can have the final deliverable ready for the customer. The team can set a date that is sooner than the deadline or the same as the deadline, but the team cannot set a date later than the deadline, without first negotiating a change to the deadline date with the customer and/or the sponsor.
   - If the team thinks that a final deliverable can be delivered before the deadline date, and an earlier delivery is a project priority, use the earlier date. (Identifying project priorities is discussed on pages 35 and 36.)
   - The deadline dates for the final deliverables are milestones for the execution phase of the project. During the execution of the project plan, the team accomplishes the tasks of the project to create the deliverables required.

4. **Add additional milestones for the execution phase of the project and assign a completion date for each milestone.**

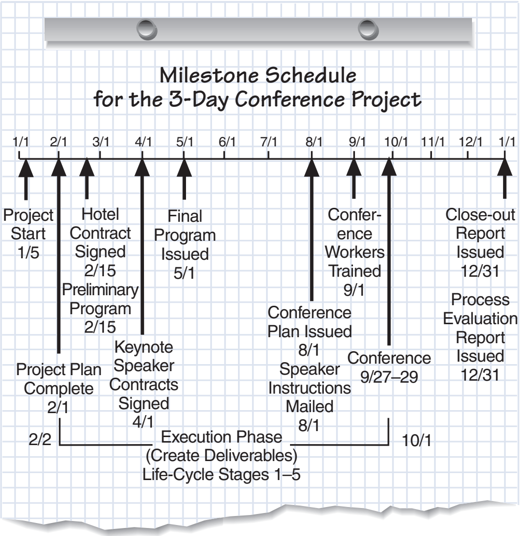
   - One useful method for determining milestones for the execution phase (when the deliverables of the project are created) is to set dates for the completion of each life-cycle stage for each final deliverable.

   - Another method is to review the list of interim deliverables and select the most significant deliverable dates for the project. (Determining what interim deliverables need to be created for the project is discussed on pages 56–60.)

Keep the total number of milestones in the execution phase to 10 or less. If there are more than 10 execution milestones, keep only those that represent the most significant accomplishments for the project and eliminate the others.

If your team will need to create other schedules, you can save the time and effort of recreating the schedule timeline by making copies of the milestone schedule and taping it to the banner paper for each schedule.

Also include milestones for the organizational deliverables for your project.



5. **Assign a risk rating to meeting the deadline date for each final deliverable. List the reasons and assumptions for each rating.**

   - Use a scale from 1–10 to assign the risk rating, with 10 as the highest risk, and 1 as the lowest.
   - A low risk rating (1–3) means there is a low degree of risk or uncertainty that the deadline date will not be met.
   - A moderate rating (4–7) means there is a moderate degree of risk or uncertainty that the deadline date will not be met.
   - A high rating (8–10) means there is a high degree of risk or uncertainty that the deadline date will not be met.

- List the assumptions, uncertainties, and risks that factor into the team's risk rating.
- If the team's risk rating is 4 or higher, reexamine the assumptions that the team made in creating the milestone schedule. List any countermeasures that could be used to decrease the risk of not meeting the deadline dates.
- If the team cannot lower its risk rating to at least a 3, add this to the issues list so that the project leader and the sponsor can discuss it.

Risk Rating Assigned by the 3-Day Conference Team

The deadline dates for the final deliverable, i.e., the conference, are September 27, 28, and 29. Team members agreed on a risk rating of 1 because they are confident that all of the necessary activities will be completed before these dates. (Or there won't be a conference!)

Don't forget to set a risk rating for each organizational deliverable. For example, the deadline date for the "Project Management Process Evaluation Report" is December 31. The team decided there would be sufficient time to prepare the report after the conference was held, so it was given a rating of 2.

Create a Deliverables Schedule

Why do it?

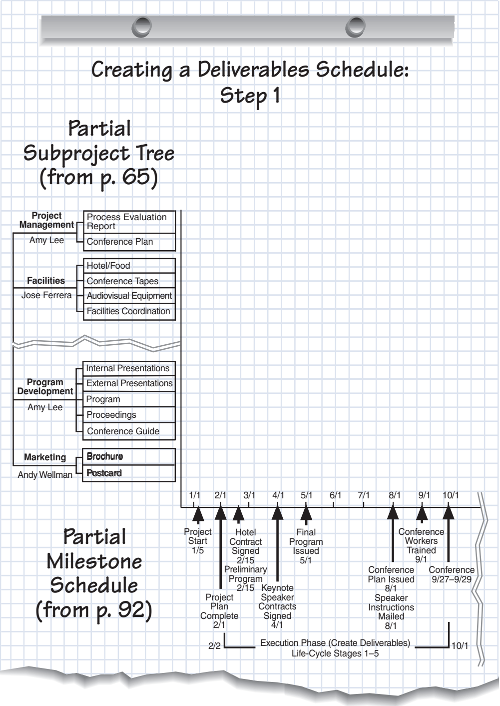
To help the team coordinate the "hand-off" of interim deliverables from one person (the supplier) to the next (the customer). A deliverables schedule shows the sequence of deliverables to be created, from first to last, and who is accountable for meeting the delivery date for each deliverable. It provides the team with a way to keep the production of the final deliverables on track.

How do I do it?

1. **Create a diagram on banner paper that will show the flow of all the deliverables that will be created for the project.**
    - To begin constructing the deliverables schedule, take a piece of banner paper, at least 10 feet long, and tape it to a wall.
    - Draw or tape a copy of the milestone schedule along the bottom of the paper to create a schedule timeline. (See pages 89–93 for instructions on how to create a milestone schedule.)
    - On one end of the timeline, draw a vertical line.
    - On the outside of the vertical line, draw the tree diagram of subprojects or simply list the names of each final and organizational deliverable for the project and for each subproject, grouped by subproject. Leave enough space to fit all of the Post-it™ Notes of interim deliverables next to the name of the final deliverable.

If a subproject team is creating its own deliverables schedule, add the subproject team's milestone dates to the project's milestone dates listed along the timeline.

To begin, tape a copy of your milestone schedule on the banner paper and draw a vertical line on one end. Next, recreate or tape a copy of the tree diagram of subprojects for your project on the outside of the vertical line. This example was created by the conference team.

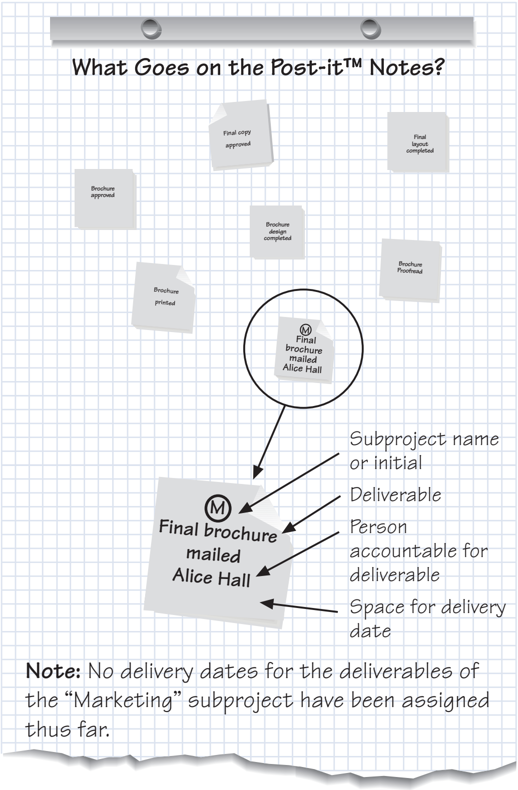


2. **Write the name of each deliverable (interim and final) on a Post-it™ Note.**
    - Include all the deliverables that will be created by both the project team and the subproject teams. These Post-it™ Notes will be used in Steps 3 and 4 to construct the deliverables schedule.
    - For type 3 projects, put the name or initials of the subproject on the top of the Post-it™ Note.
    - On each Post-it™ Note, add the name of the person who is accountable for the deliverable.
    - Leave space on the lower right corner of the Post-it™ Note to add a delivery date. If a deliverable already has an assigned delivery date, add it to the Post-it™ Note now.

It will save time if team members create the Post-it™ Notes for their subprojects and then bring them to the team meeting.

Don't forget to complete Post-it™ Notes for each organizational deliverable for the project, and for any interim organizational deliverables.

This illustration shows at a glance the instructions that are described in Step 2 of the activity "Create a Deliverables Schedule."



What Goes on the Post-it™ Notes?

Note: No delivery dates for the deliverables of the "Marketing" subproject have been assigned thus far.

3. **Place the Post-it™ Notes created for the final deliverables at the appropriate points on the diagram.**

   - Align the final deliverables with their delivery dates (along the timeline) and with the correct branches of the subproject tree (along the side of the diagram).

4. **Align the interim deliverables with the final deliverables and the timeline.**

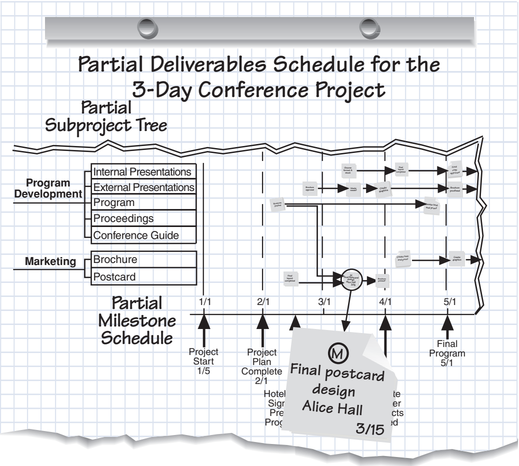
   - Place each interim deliverable in line with the appropriate final deliverable and in line with the estimated delivery date for the interim deliverable.
   - If any of the interim deliverables are major milestones, align them with the milestone dates.
   - Draw arrows from each interim deliverable to the next interim or final deliverable in the chain. Arrows represent the activities required to transform one deliverable into another.

First try to align the interim deliverables with the milestone dates. If that doesn't work, align the interim deliverables so that the final deliverable dates are met, and then revise the major milestone dates.

The team needs to capture each deliverable that moves outside a subproject. Deliverables that will stay within a single subproject do not need to be included in the deliverables schedule because these deliverables are within the area of responsibility of the subproject and will be monitored by the subproject team.

Place the Post-it™ Notes for the organizational deliverables (and interim organizational deliverables) on the banner paper, aligning them with the timeline and the correct branches of the subproject tree.

5. **Add delivery dates to the Post-it™ Notes for the deliverables.**
   - Write the delivery date in the lower right corner of each Post-it™ Note.
   - The delivery dates for the final deliverables should be no later than the deadline dates. If this is not the case, go back and try to align the interim deliverables so that the deadline dates will be met. If this is not possible, put it on the issues list to resolve with the sponsor.



6. Review the major milestones, and revise if necessary.

- Add more important delivery dates, and delete less important ones.
- If there are more than 10 execution phase milestones, put them in order of priority, and delete the less important ones.

One way to tell if you have a true major milestone is to look for places where several deliverables feed into another deliverable. This indicates that several parts of the project have come together. Milestones, however, must ultimately be chosen based on the team's perceptions of the most important accomplishments of the project.

Interim Deliverables and Milestone Dates for the 3-Day Conference

The project team decided that the subproject interim deliverables "postcard mailed" and "brochure mailed" were critical dates for the project and added them to the milestone schedule. The interim deliverable "speaker instructions mailed" was deleted.

7. **Place an asterisk on the Post-it™ Notes where the customers' acceptance criteria for the deliverable needs to be clarified.**
    - Get agreement on the criteria outside the team meeting. The criteria should be written down as part of the documentation for the project plan.

8. **Revisit the team's risk ratings for meeting the deadline dates for the final deliverables. Revise if necessary.**
    - Use the milestone schedule that the team created to check dates and risk ratings.
    - Now that the team has more detailed information about the interim deliverables, their interdependencies, and their targeted delivery dates, it's a good idea to reassess the team's risk ratings.
    - If the team's risk rating is 4 or higher, reexamine the assumptions that the team used in creating the deliverables schedule. List any countermeasures that could be used to decrease the risk of not meeting the deadline dates.
    - If the team cannot lower its risk rating to at least 3, add this to the issues list so that the project leader and the sponsor can discuss it.

In choosing the best countermeasures, the team should base its decisions on the priorities of the project—lower cost, earlier delivery, or more features of the final deliverable. For example, if the schedule takes precedence over the budget, then any countermeasures that will ensure the schedule is met, but will cost more money, are still good options.

Create an Activity Schedule

Why do it?

To create a schedule of the activities required to create all of the interim and final deliverables. The activity schedule allows the team to make sure that each activity is completed at the appropriate time, which ensures that the final deliverable will also be completed on time.

How do I do it?

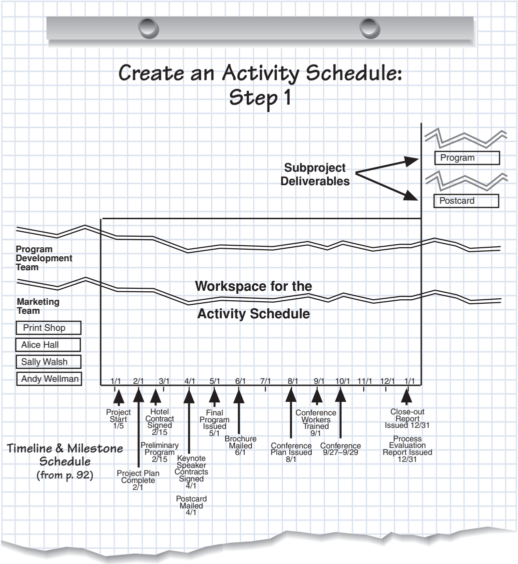
1. **Create a diagram on banner paper that will show the flow of all the activities that need to be completed for the project.**
    - To begin constructing the activity schedule, take a piece of banner paper, at least 10 feet long, and tape it to a wall.
    - Draw or tape a copy of the milestone schedule along the bottom of the paper to create a schedule timeline. (See pages 89–93 for instructions on how to create a milestone schedule.)
    - On both ends of the timeline, draw a vertical line.
    - On the outside of the left vertical line, write the names of the people who will be responsible for getting the activities of the subproject completed (or the activities of the project if you have a type 1 project). Leave enough space to fit all the Post-it™ Notes of activities next to each name.
    - Separate the names of team members from the non-team members.
    - Draw a horizontal line across the diagram. This line should be above all the names of team members and non-team members and should extend from one end of the diagram to the other.

- Above the horizontal line, and to the right of the right vertical line, list the deliverables for either the project or the subproject, depending on what project type the team has.
  - **For type 1 projects (this schedule is optional):** The project team should list the final deliverables and organizational deliverables for the project.
  - **For type 2 projects:** The project team should list the final deliverables and the organizational deliverables for each subproject, or tape a copy of the tree diagram that shows the deliverables by subproject.
  - **For type 3 projects:** The subproject team should list the final deliverables and the organizational deliverables for the subproject, or tape a copy of the part of the tree diagram that is specific to the subproject.

If a subproject team is creating its own activity schedule, add the subproject team's milestone dates to the project's milestone dates listed along the timeline.

2. **Identify all the activities that must be accomplished to create each interim and final deliverable.**
   - Write each activity on a Post-it™ Note. Leave space on the Post-it™ Note to write the name of the person who is responsible for the activity, and space for the start and end date of the activity.
   - Teams with type 2 projects will be completing an activity schedule for the project as a whole. Each team member should identify the activities that he or she will be carrying out for his or her subproject.

To begin, tape a copy of your milestone schedule on the banner paper and draw vertical lines at each end of the timeline. On the left end, write the names of the people who are responsible for the activities, both team members and non-team members. Draw a horizontal line above these names, from one end of the diagram to the other. This example was created by the Marketing subproject team of the 3-day conference.



- Teams with type 3 projects will be completing an activity schedule for each subproject, but not for the project as a whole. Each subproject team member should identify the activities that he or she will be carrying out.
- One way to identify activities is to refer to the arrows on the deliverables schedule. These arrows represent the activities required to transform a deliverable into the next deliverable in the sequence, ending with the final deliverable. If the team translates each arrow into an activity or set of activities, all of the activities for each final deliverable will be captured, in the order in which they will occur.
- In the space above the horizontal line of the diagram, line up the activities needed to create each deliverable with the appropriate final deliverable or subproject listed on the righthand side of the diagram. Sequence the order of activities from left to right on the diagram.

Be sure to include review activities and countermeasures as Post-it™ Notes since these are also activities.

To make it clear which activities belong with each final deliverable, use different color Post-it™ Notes to see the flow of activities for any specific deliverable.

Don't forget to create Post-it™ Notes for activities that will create the organizational deliverables.

3. **Vertically align the activities so that they meet the delivery dates for the appropriate deliverable.**
    - Use the delivery dates from the deliverables schedule.
    - Adjust the delivery dates, if necessary, to create a workable schedule that meets the deadlines.
    - After aligning all the activities, write the start date in the lower left corner of the Post-it™ Note and put the end date in the lower right corner.

After all of the activities have been assigned a start and end date, the critical path can be calculated. (This is optional.) The critical path is the shortest possible path from the first activity to the last. Refer to The Memory Jogger™ II, *pages 5–7, for instructions on calculating the critical path.*

If you adjust an activity end date, which then changes the team's delivery date for a deliverable, make sure the revised delivery date does not exceed the deadline date for the deliverable, if it has one. If the revised delivery date exceeds the deadline date, put this problem on the issues list and resolve it with the sponsor and/or the customer.

4. **Move all the Post-it™ Notes below the horizontal line of the diagram, aligning each activity with the person who is responsible for completing it.**
    - Move the Post-it™ Notes to align them with the name of the person who is responsible for completing the activity. Keep each Post-it™ Note aligned with the completion date for the activity.

- Add to each Post-it™ Note the name of the person who is responsible for completing the activity.

Make sure that you haven't assigned more work than each person can accomplish by the completion dates required. If you have, either reassign an activity or adjust the schedule.

5. **Using arrows, connect one activity to the next activity in the chain.**

   - In the deliverables schedule, the arrows represent activities. In the activity schedule, the arrows represent deliverables.

Check the arrows to see if they represent deliverables (which they should) or activities (which they shouldn't). If any arrows actually represent activities, replace the arrow with a Post-it™ Note of the activity.

For type 3 project teams: *If any of the arrows go outside the subproject, make sure the deliverable created as a result of this activity is included on the deliverables schedule.*

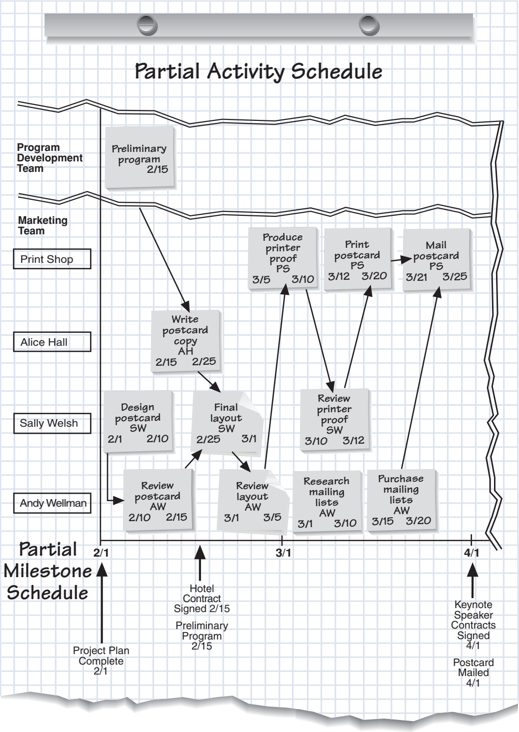
6. **Assign a team coordinator to any activity that will be completed by someone outside the project team.**

   - Assign someone from the team, (or in the case of subprojects, someone from the subproject team), who will be accountable for making sure the activity gets done.
   - Put the coordinator's name on the Post-it™ Note and mark it with a "C." This will remind the team which activities need to be coordinated and who is responsible for coordinating them.

7. **For each review listed in the review and approvals table, add a start and end date in the table.**
   - Creating a reviews and approvals table is described in the section called "Complete the List of Required Reviews & Approvals" on pages 69–72.

8. **Revisit the team's risk ratings for meeting the deadline dates for the final deliverables. Revise if necessary.**
   - If the team's risk rating is 4 or higher, define some countermeasures that will decrease the team's risk to at least a 3. If the team cannot lower its risk to at least 3, add this to the issues list to resolve with the sponsor.

This illustration shows some of the activities to be completed by the Marketing subproject team of the conference project to produce the postcard.



Draw a Gantt Chart

Why do it?

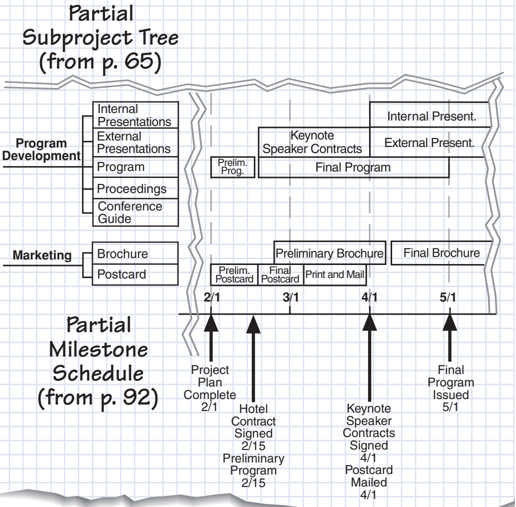
To display the major activities of the project and their duration. The Gantt chart helps both the team and people outside the team to understand the major activities of the project and their progression in time.

How do I do it?

1. **Using the deliverables schedule, draw a bar around each deliverable that extends from the start date of the first activity to the date of the last activity.**
   - The bar indicates the amount of time that it will take to complete all the activities that are needed to create the deliverable.
   - Inside the bar, write the name of the overall activity that the bar represents and the person who is accountable for making sure the deliverable gets created.
   - There will be one bar for each interim deliverable, which means there will be more than one bar in line with each branch of the tree diagram (or with each final deliverable listed on the outside of the left vertical line).
   - Remove the deliverables Post-it™ Notes from the schedule.

Before you begin, make sure you've made a copy of the deliverables schedule.

Partial Gantt Chart of Activities for the 3-Day Conference Project



Estimate the Staff Effort Required

The time that people in an organization expend on a project can be a major expense. It is necessary to estimate the time required to complete the project in order to make the needed resources available. And, if an organization wants to know whether its commitments to one project will interfere with other projects or assignments, it is crucial to create a staffing forecast for the work effort needed on the project. The staffing forecast is an estimate of this effort per day, week, or month, for the duration of the project.

When you need to:	Do this activity:	Page
Estimate the total amount of time that people will be working on the project.	Estimate the Total Staff Time Needed	113
Calculate the amount of time people will spend on the project to avoid exceeding the staffing limit before the work is done.	Create a Staffing Forecast	118
Verify that the project effort assigned to an individual or subproject does not exceed his or her availability.	Create a Staffing Forecast	118
Project the amount of time that each individual and/or subproject will spend during each time period of the project.	Create a Staffing Forecast	118

Estimate the Total Staff Time Needed

Why do it?

To determine the total amount of staff time that will be required to complete the project. The staff time estimate tells the team if the project can be completed within the staffing limit defined by the sponsor.

How do I do it?

1. **Estimate the amount of staff time needed for each subproject or each individual that will work on the project.**
   - **Type 1 projects**—Each team member should use this formula:

     # hours or days per week (or month) X # of weeks or months the team plans to meet.

     Add up the individual hours to get a total estimate.
   - **Type 2 projects**—Time needed for each person to complete his or her subproject. Add up the estimates for each subproject to get a total estimate.
   - **Type 3 projects**—Time needed for each subproject team to complete the subproject. Each subproject leader and his or her team work together to prepare an estimate for each person on the subproject. Add up the individual estimates for each subproject to get a total estimate for each subproject.
   - Make the estimate in hours, weeks, months, or years, as appropriate.

Don't estimate time for any work that is outside the scope of the project. Also, you may not need to estimate time for people who will be charged as overhead. If you're not sure how to deal with overhead charges, check with the sponsor.

If the team is planning to do a staffing forecast where staff time is estimated by time period, go ahead and do that first. The team will have the totals by individual or subproject to use for the estimate.

Don't forget to take into account any constraints on the project that relate to staffing.

2. Rate the accuracy of the total estimate.

- The accuracy rating indicates how comfortable the team (or subproject team) feels that the estimate is an accurate prediction of how much time will be spent on the project.
- Use the letters H, M, and L (high, medium, and low) to indicate your team's (or subproject team's) confidence in the estimate.

  H = actual staff time could vary by ±10% from the estimate

  M = actual staff time could vary by ±25% from the estimate

  L = actual staff time could vary by ±50% or more from the estimate
- A low accuracy rating means that the team doesn't really know, the estimate is just a guess.
- List the reasons for the rating.

If the accuracy rating is medium or low, and if the estimate is below the staffing limit, the team might consider adding some additional time to the estimate to cover the uncertainty of the estimate.

3. **Compare the team's estimate to the sponsor's limit on staff time, if any.**
   - If the sponsor did not set a limit on staff time, the team should review the assumptions that were made in creating the estimate to make sure they were sound, and to be confident that this is the best estimate the team can make at this time.
   - To compare the estimate to the limit, calculate a range (±) for the estimate, based on the accuracy rating assigned to it. For example, if the team has an estimated staff time of 100 hours, with a high accuracy rating equivalent to a range of ±10%, the estimate could vary by 10 hours, more or less. The hourly range for the estimate is 90 to 110 hours. (The range for each accuracy rating—high, medium, or low—is listed in Step 2.)
   - If the high end of the range is close to the limit, either slightly under or even slightly over, and the assumptions for creating the estimate are sound, then the team should move on to the next planning activity. Staff time is difficult to estimate and it's not worth the effort trying to improve the estimate if it is already close to the limit.
   - If the high end of the range is either much higher or much lower than the limit, the team should check the assumptions that were made in creating the estimate to make sure they were sound. If the assumptions are sound, list the reasons for the deviation from the limit and put staff time on the issues list for the project leader to discuss with the sponsor.
   - If the high end of the range is over the limit, list the assumptions that the team used to create the estimate and put the issue on the issues list for the project leader to resolve with the sponsor.

The team does not need to use the ranges given in Step 2 if it has a more accurate estimate. For example, the team might feel that an estimate with a high accuracy rating is within a ±5% range instead of ±10% range. In this case, the team should use the ±5% range. Remember, it is never possible to predict with 100% certainty.

Estimates of Staff Time Required for the 3-Day Conference

The conference is a Type 3 project, so subproject efforts have been estimated.

Subproject	Staff Time in Hours
Marketing	250 hours
Facilities	350 hours
Registrations	200 hours
Program Development	475 hours
Project Management	100 hours

Total estimate = 1,375 hours = approximately 8 months (M)
1,375 hours/40 (hours per week) = 34.375 weeks
34.375 weeks/4.3 (weeks per month) = 7.99 months

Accuracy rating = Medium (M)
Staff time range for medium rating (±25%) = 1,030 to 1,720 hours

Reason for rating: We have a general idea of how much time the project will take because we had a conference last year. Unfortunately, we did not keep good records of the actual time that staff put into the project, so we think the rating is moderately close.

Staffing Limit: None

Even though there is no staffing limit, the sponsor has asked our team to monitor the actual hours that are invested in the project.

Create a Staffing Forecast

Why do it?

To assess when people's time will be required over the course of the project. The staffing forecast gives credibility to the team's request for human resources and it is useful for tracking whether or not staffing expenditures are ahead of or behind the budgeted amount.

How do I do it?

1. **Calculate the amount of time that each person or subproject will spend on the project by time period (day, week, month, or quarter).**

   - The timeframe used for calculating the forecast depends on the activity level in the project. For example, a long-term project with very little ongoing activity may need to monitor staff time every month, while another long-term project with a lot of activity will need to monitor staff time every week.
   - Subproject team leaders should ask each individual subproject team member to estimate his or her effort by time period, and then he or she can add the estimates together. The project team adds up the subproject estimates to get the project estimate.
   - If your project is type 1 or 2, and your team thinks that a staffing forecast is needed, ask each individual to estimate his or her effort by time period, and then add the estimates together.

If the subproject team created an activity schedule, an easy way to determine the staff time by time period is to calculate the amount of time each activity or set of activities will require. Write the time allotted for each activity on the chart and then record the total time per person, per time period, at the bottom of the chart. The team can then see the schedule and staff time allotments in one chart.

2. **Make adjustments if there are staffing conflicts within the project or with other projects or assignments.**
   - If adjustments cannot be made for over-commitments (without affecting the deadline dates), put this issue on the issues list so that the project leader and sponsor can resolve the problem.

3. **Add up the total and cumulative hours for each time period.**
   - The cumulative total in the final time period should match the total staff time estimate.

Staffing Forecast for the 3-Day Conference

Staff Time in Hours

Subproject	**Jan.**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Marketing	16	16	42	48	72	32	4	4	4	4	4	4
Facilities	32	10	40	10	4	4	40	60	130	12	4	4
Registrations	4	4	4	4	6	12	18	50	86	4	4	4
Program Development	70	66	75	40	40	40	40	12	80	4	4	4
Project Management	8	8	6	6	6	12	12	8	8	8	8	10
Staff Time in Hours	130	104	167	108	128	100	114	134	308	32	24	26
Cumulative Staff Hours	130	234	401	509	637	737	851	985	1,293	1,325	1,349	**1,375**

Create a Project Budget

Whenever a project will incur costs, either internally or from external purchases, the team needs to estimate those costs so that the organization knows how much money should be allocated to the project. If it is important for the organization to know when the money will be spent, the team needs to create a spending forecast.

When you need to:	Do this activity:	Page
Show a breakdown of how money will be spent during the project.	Estimate Costs	122
Plan cash flow.	Create a Spending Forecast	128
Track spending as it occurs so that costs don't exceed the spending limit for the project.	Create a Spending Forecast	128

Estimate Costs

Why do it?

To determine the amount of money that the organization should allocate for both internal and external costs of the project. A cost estimate tells the team whether or not it will be able to complete the project within the spending limits set by the sponsor.

How do I do it?

1. **Estimate the cost for staffing the project and the cost for other internal charges and calculate the total internal cost for the project.**
   - Costs are considered internal when money is being spent inside the organization. Internal costs consist of staff costs and other charges such as internal supplies, copies, materials from an inside group, and equipment charges.
   - Estimate internal costs when they will be part of the costs tracked during the project, or when the sponsor requests them. Usually staff costs are estimated when the customer will be paying for these charges directly.
   - To get a staffing cost:

     a) Use your team's estimates for the amount of staff time needed from each team member or each subproject;

     b) Multiply these numbers by the appropriate billing rates, e.g., an hourly, weekly or monthly rate;

     c) Add these numbers together to calculate the total cost of staffing the project.

- To calculate the total for internal costs, add together the staffing cost and the cost for internal charges.

> *If you don't know the rate for each team member or subproject, ask the sponsor what billing rate you should use.*

2. **Estimate any external costs and calculate the total for external costs.**
   - External costs are purchases made from outside suppliers. Examples are: contract labor, purchased materials, travel, and equipment rental or purchase.
   - External purchases are usually made with a purchase order, expense account, or blanket order.
3. **Add together the estimate for internal costs and the estimate for external costs to get an estimated total cost for the project.**

> *Make sure that all the costs included in the total estimate relate to the project scope. For example: As a result of your team's project, one of the departments in your organization will need to retrain its people or add new equipment. If this is an issue, be sure to add it to the issues list so that it can be resolved with the sponsor.*
>
> *Don't forget to take into account any constraints on the project that relate to spending.*

4. **Assign an accuracy rating to each estimate for internal costs, external costs, and the total project cost.**
    - The accuracy rating indicates how comfortable the team feels that the estimates are an accurate prediction of what will be spent.
    - Use the letters H, M, and L (high, medium, and low) to indicate your team's confidence in the estimates.

      H = actual costs could vary by ±10% from the estimates

      M = actual costs could vary by ±25% from the estimates

      L = actual costs could vary by ±50% or more from the estimates
    - A low accuracy rating means that the team doesn't really know, the estimates are just guesses.
    - Consider the accuracy of the estimate of staff time required for the project in determining the accuracy of the total estimate for internal costs.
    - List the team's reasons for each accuracy rating.

> *If your team has an accuracy rating of medium or low for an estimate, and the estimate is below the spending limit, consider adding some additional moneys to the budget to offset the risk of running out of money because the estimate was too low.*

5. **Compare the team's cost estimates to the sponsor's limits on spending, if any.**
    - Compare only those estimates that the sponsor has set a limit on. For example, if the sponsor set a limit only on the total project cost, then the team needs to compare the total cost estimate to the sponsor's spending limit on the total project cost.

- If the sponsor did not set a spending limit, the team should review the assumptions that were made in creating the estimate to make sure they were sound, and to be confident that this is the best estimate the team can make at this time.
- To compare the estimate to the limit, calculate a range (±) for the estimate, based on the accuracy rating assigned to it. For example, if the team has an estimated cost of $100, with a medium accuracy rating equivalent to a range of ±25%, the estimate could vary by $25, more or less. The dollar range for the estimate is $75 to $125. (The range for each accuracy rating—high, medium, or low—is listed in Step 4.)
- If the high end of the range is over the limit, list the assumptions the team used to create the estimate and put the issue on the issues list for the project leader to resolve with the sponsor.

The team does not need to use the ranges given in Step 4 if it has a more accurate estimate. For example, the team might feel that an estimate with a high accuracy rating is within a ±5% range instead of ±10% range. In this case, the team should use the ±5% range.

Cost Estimates for the 3-Day Conference

These tables show the breakdown of all the estimated costs for the conference. The tables represent the work done in Steps 1 through 5 on pages 122-125.

Internal Costs	Cost Items	Staff Time (in Hours)	Hourly Rate	Total Cost
Staffing Costs				
Marketing	N/A	250	$25	$6,250
Facilities	N/A	350	$25	$8,750
Registrations	N/A	200	$25	$5,000
Program Development		475	$25	$11,875
Project Management	N/A	100	$25	$2,500
			Subtotal	**$34,375**
Other Internal Costs				
Marketing Materials	Brochures, postcards	N/A	N/A	$25,000
			Subtotal	**$25,000**
Estimated total internal costs				**$59,375 M**
Reason for medium rating: More than 50% of the internal costs are staffing costs and the staff time estimate was given a medium accuracy rating.				

Continued on next page

Cost Estimates for the 3-Day Conference (continued)

External Costs	Cost Items	Staff Time (in Hours)	Hourly Rate	Total Cost
Hotel (staff)	The Madison	N/A	N/A	$10,000
Food (based on 300 people)	The Madison	N/A	N/A	$42,400
Audiovisual Company	TBD	N/A	N/A	$25,000
Travel	Staff/ speaker travel	N/A	N/A	$5,000
Additional moneys to offset unknown costs				**$3,000**
Estimated total external costs (Range = ±5% or $4,270) **Reasons for high rating:** The costs for the hotel and food are established by contractual agreements and audiovisual costs are based on prior experience. Travel expenses are variable, depending on the speakers selected and their locations, so additional moneys have been added to the budget to allow for the unknown cost.				**$85,400 H ($81,130 to $89,670)**
Estimated Total Project Cost				**$144,775**

Sponsor's Cost Limit: **$90,000** for external costs only. The team's estimate for external costs is **$85,400** and was assigned a high accuracy rating equivalent to a ±5% range, so the upper range of the estimate ($89,670) is under the sponsor's limit.

Create a Spending Forecast

Why do it?

To project when the money for the project will be spent. The spending forecast gives credibility to the team's cost estimate and it helps the team monitor the spending levels of the project.

How do I do it?

1. **Assign the costs for the project to the week, month or quarter in which the cost will be committed or actually spent.**
    - An easy way to distribute the costs is to match each cost to an activity or set of activities in the activity schedule. (The activity schedule is described on pages 102–109.) Then simply write the costs under the appropriate time period along the bottom of the chart. This will allow the team to see the schedule and costs by time period in one chart.
    - Add up the total and cumulative costs for each time period.

If internal costs must be forecasted, first complete a staffing forecast, then calculate staffing costs by time period. Distribute the other internal costs as appropriate.

Don't spend too much time trying to make the forecast perfect. Make the best guess possible.

Spending Forecast for the 3-Day Conference

The table below shows just a part of the spending forecast for the conference.

Cost Category	Costs (in dollars)				
	January	February	March	April	May
Staff Costs	3,250	2,600	4,200	2,700	3,200
Internal Charges			5,000		7,000
External Costs		1,000			
Additional moneys					
Monthly Total	3,250	3,600	9,200	2,700	10,200
Cumulative Total	**3,250**	**6,850**	**16,050**	**18,750**	**28,950**

Assemble the Project Plan

Once the team has completed the activities that are required to produce a project plan, it's time to assemble the plan and get it approved. The plan describes what the team will do as it begins to execute the project. The plan should include an executive summary and all of the documents, tables, lists, etc., that were produced in the planning process. Once the plan is assembled, it needs to be reviewed with the sponsor and customer, approved, and then distributed to all of the key stakeholders of the project.

When you need to:	Do this activity:	Page
Get approval to move forward with the project.	Assemble the Project Plan	131
Make sure everyone has the same game plan for the project.	Assemble the Project Plan	131
Create one information source to answer project-related questions by anyone at any time.	Assemble the Project Plan	131

Assemble the Project Plan

Why do it?

To create a document, sometimes referred to as "the project book," that details the project plan. The plan describes how the team envisions doing the project, and after it is approved, it provides the team with a roadmap for executing the project. The project book is also the "answer book" for team members, stakeholders, the project leader, and the sponsor.

How do I do it?

1. **Create an executive or leadership summary for the project plan.**
   - The summary's components and organization will vary according to your team's project and preferences, however, your team may want to use the outline on the next page to get started.

Generic Components of a Leadership Summary

Project Scope

- List the name and objectives of the project.
- Describe the deliverables to be produced by the project, the life-cycle stages of each final deliverable, and the customers' criteria for accepting each final deliverable.
- List any organizational goals for the project.

Don't forget about any organizational deliverables that are required by your project. You'll need to describe them, and include their life-cycles and the sponsor's criteria for accepting each one.

Project Scope Risk

- Summarize the key risks of creating the final deliverables and describe the key countermeasures selected by the team to reduce the risk for each deliverable.

Project Resources

Team Membership: List the regular and ad hoc members of the team.

Schedule: Show the milestone schedule and the deadline dates. Define the team's risk rating for meeting the deadline dates and list the key countermeasures selected by the team to reduce the risk of not meeting the deadline dates.

Staff Time: List the estimate for the total staff time required for the project, including the accuracy rating for the estimate. Indicate the staffing limit, (if there is one), whether the estimate exceeds the limit, and if it does, the reason(s) why the estimate exceeds the limit.

Budget: List the total estimate for internal and external costs, and the total estimate for the project. Indicate the spending limit, (if there is one), whether the estimate exceeds the limit, and if it does, the reason(s) why the estimate exceeds the limit.

Other Issues

- List any other key issues, including those related to project boundaries.

2. **Assemble the project plan.**

- Include the following sections:
  - – Original Charter
  - – Team Guidelines
  - – Project Scope
  - – Required Reviews and Approvals
  - – Project Scope Risk
  - – Required Reports
  - – Team Membership
  - – Schedule(s)
  - – Staffing Estimates and Forecast (if required)
  - – Budget Estimates and Forecast (if required)
- Attach tables, charts, and other diagrams as appropriate.

The team's project plan will be easier to read and refer to if it has some of the same characteristics of a real book, that is, a cover, a table of contents, tabs that divide each section, and a date of publication. The project book must be updated and "reprinted" as changes are made to the plan. The project book can even be published electronically.

3. **Review the project plan.**

- All the team members of the project should be involved in reviewing the plan. If this isn't feasible, choose the team members who represent a good cross section of the organization.
- Do a "sanity" check to make sure the plan is complete and accurate.

4. **Review the plan with the sponsor and customer, if appropriate.**
    - Make revisions to the plan as needed, based on sponsor and customer input.
5. **Sign and distribute the plan.**
    - The team members, the sponsor, and the customer, when appropriate, should sign the project plan. This is the contract that the team will use in moving forward with the project.
    - Distribute the plan to team members, the sponsor, customers, and all key stakeholders of the project.

Chapter 5

Doing the Project

Now that the project plan has been completed and approved, it's time to execute the plan, which means creating the deliverables according to the customers' criteria for acceptance, within the limits of the budget, and according to the timelines outlined in the schedule. At this point, the team needs to anticipate potential problems and address requests for changes to the project plan. As the plan is being executed, the team needs to meet regularly to review the status of the project. In addition, both the customer and the sponsor need to be kept informed of the project through regularly scheduled review meetings with the team.

When you need to:	Do this activity:	Page
Track the execution of the project.	Monitor Project Progress	136
Deal with problems or make changes to the plan.	Resolve Problems and Manage Change	141
Review the progress of the project with the project team.	Hold Project Team Meetings	146
Review the progress of the project with the sponsor or customer.	Hold Project Review Meetings	150

Monitor Project Progress

Why do it?

To ensure that the project is moving forward as planned. Monitoring project progress gives the team a warning system for problems with the project, which allows the team to resolve them early and avoid more costly changes later on.

How do I do it?

1. **Determine how often the schedule, staff time, and budget "actuals" should be monitored.**
    - Actuals are the real expenditures of money or staff time during the project, or the completion dates of scheduled activities for the project.
    - How often the actuals are tracked or monitored depends on how fast the work of the project is being done. For example, if a project will last only two months, actuals should be tracked at least once a week. If the project will last two years, actuals should be tracked at least once a month.
    - Typically, the project leader monitors the main project, and subproject leaders monitor the subprojects.
    - Monitor subprojects at least as often as the main project.

If your team did a forecast for spending or staff time as part of the project plan, monitor these forecasts according to the periods that are defined in the forecasts.

2. **Compare the schedule, staff time, and budget actuals to the plan, and calculate any variances.**

    - A variance occurs when the project is behind or ahead of the plan. Variances can be positive (the project is ahead of schedule) or negative (the project is over budget). Critical variances indicate the project as a whole is off track.

    - The project leader can determine if the project is ahead of, behind, or on schedule by comparing the actual completion dates with the projected completion dates (as defined in the milestone, deliverables, and activities schedules that are described in Chapter 4).

    - For example, to calculate the schedule variance for a deliverable or for the completion of a scheduled activity, subtract the date an activity or delivery actually occurred from the date it was scheduled to occur. These calculations provide the schedule variance in days or weeks.

Variance Calculation Sheet for the 3-Day Conference

Completed May 31

Project Plan Area	Project Plan (including changes)	Actual Project Results	Variance	Explanation
Schedule (completion dates)				
Issue Final Program	5/1	5/4	3 days	Amy Lee was out sick for a week, which delayed the program.
Complete Review for Preliminary Brochure	5/18	5/20	2 days	The delay in issuing the program created a delay in completing the brochure.
Staff Time				
Cumulative Hours Expended	985 hours	1,075 hours	90 hours	Preparation of the marketing materials took longer than projected.
Budget				
Internal Charges	N/A	N/A	N/A	N/A
Cumulative External Charges	$29,450	$28,950	$500	Hotel deposit was $500 less than planned.
Total Cost	N/A	N/A	N/A	N/A

If your team completed staff time and spending forecasts as part of the project plan, it's easy to calculate a variance. Simply subtract the cumulative actuals from the cumulative estimate in the plan. If your team did not do any forecasts, the project leader will have to decide whether staffing and spending expenditures comply with the plan.

3. **Decide what action should be taken, given the kind of variance found.**

   - If there is no variance in the schedule, staff time, or spending, and the numbers are accurate, the project is likely on course.
   - If there is a positive variance, determine the reason for the variance.
   - If there is a negative variance, the team will need to take further action. Is there a reasonable explanation for the variance? Is the variance a cause for concern?
     - If the variance is not a cause for concern, simply report an explanation for the variance.
     - If the variance is a cause for concern and can be resolved easily (without changes to the plan), then resolve it. If the variance cannot be resolved easily, put it on the issues list with the date required for its resolution. If the action to resolve the variance requires changes to the project plan, use the flowchart on page 145 as a guide in making changes to the plan. (The activity "Resolve Problems and Manage Change" on pages 141–145 describes the process for making changes and includes this flowchart illustration.)

Although a positive variance is generally good, it still indicates that the project has deviated from the project plan. Perhaps something is missing or a problem exists that could produce negative effects later on. Examine the reasons for every variance, positive and negative. If there is potential for future problems, create countermeasures to eliminate or reduce the probability of these problems occurring.

Actions Taken on May Variances (for 3-Day Conference)

No actions are required because:

1. The three-day delay in issuing the final program delays the brochure but does not affect other activities.
2. The two-day delay in the brochure is not critical to the project.
3. Staff time is being tracked but has no set limit.
4. There is a $500 positive variance because the required hotel deposit is less than the team anticipated, but this variance will disappear when the final hotel bill is paid.

Resolve Problems and Manage Change

Why do it?

To respond to problems or requests for changes to the project plan. Having a process for managing change gives the team a way of revising the project plan, when needed, so that the project stays focused on satisfying the customer.

How do I do it?

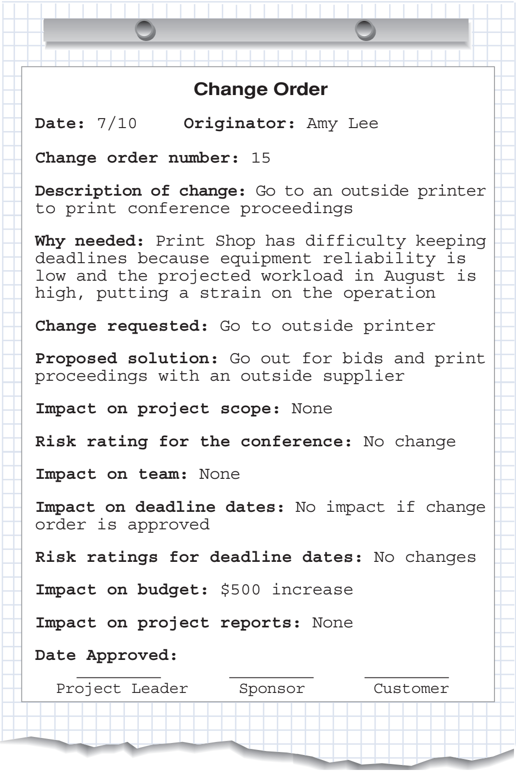
1. **When a change is proposed, decide whether or not it is a good idea.**
   - Requests for changes may come from someone outside of the team, such as the sponsor or a customer. Also, as team members are monitoring any changes in the environment, they may need to propose changes that will address a problem that has occurred or has the potential to occur. Changes in the environment include organizational, regulatory, competitive, and technological changes that could have an impact on the project.
   - Not every proposed change should be adopted. Be sure to ask, "Is this change good for the customer? The organization? The project?"
   - If the change will not add value to the project, put it on the issues list to resolve with the person who requested the change.
2. **If the change is a good idea and doesn't require modifying the project plan, implement it.**
   - If the change doesn't modify the project scope, customer acceptance criteria, schedule, staff time, budget, or risk level of the project, implement it.

3. **If the change requires modifying the project plan, define the impact on the plan and prepare a change order.**
    - A change order is a one-page description of the proposed change and its impact on the project. How will the change affect the risk level of the project? The cost? The schedule?
    - Most parts of the project plan are interdependent, meaning that if one part of the plan is changed, other parts will likely need to be changed as well. For example, if a change to the project scope is required, it will probably affect the schedule, staff time, budget, risks of creating the deliverables, and reviews and approvals needed. Be sure the team examines all the ramifications of a requested change.

A change to the project plan is really a miniproject and therefore the team needs to follow the same set of steps that it did to create the original project plan. However, if the changes are simple, the team can go through the steps quickly.

Let the priorities of the project guide the team in deciding how to modify the project plan. For example, if the schedule is most important and a change has been requested to the scope of the project, look for ways to change the staff time and budget before modifying the schedule.

Amy Lee found out that the Print Shop was having equipment problems and this would delay the printing of the conference proceedings, which were critical. An outside printer quoted a higher charge than was budgeted, so a change order had to be submitted to the project team and the sponsor.



Change Order

Date: 7/10 **Originator:** Amy Lee

Change order number: 15

Description of change: Go to an outside printer to print conference proceedings

Why needed: Print Shop has difficulty keeping deadlines because equipment reliability is low and the projected workload in August is high, putting a strain on the operation

Change requested: Go to outside printer

Proposed solution: Go out for bids and print proceedings with an outside supplier

Impact on project scope: None

Risk rating for the conference: No change

Impact on team: None

Impact on deadline dates: No impact if change order is approved

Risk ratings for deadline dates: No changes

Impact on budget: $500 increase

Impact on project reports: None

Date Approved:

Project Leader ______ Sponsor ______ Customer ______

4. Have the change order approved, and implement the change.

- Usually the project leader and the sponsor approve the change order.
- Customers should also approve the change order if the change will affect them.

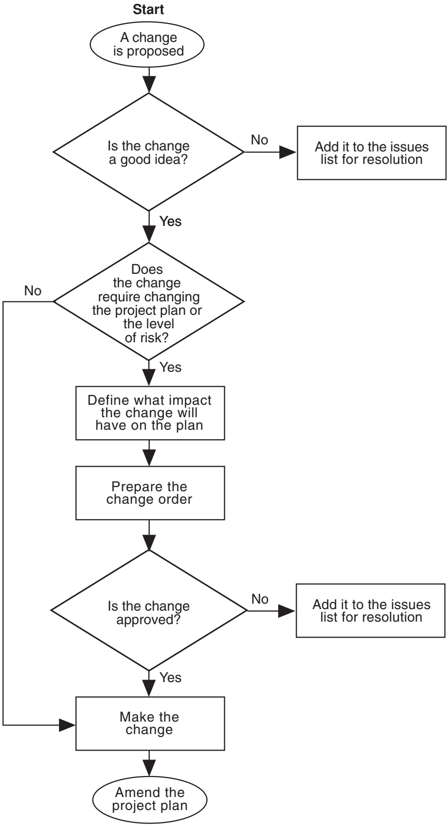
The customers of the 3-day conference are not available to the project team and therefore are not involved in managing change. The sponsor approved the change order for an increase to the budget.

5. Update the project plan to incorporate the change.

- It is the project leader's responsibility to incorporate the change by amending the appropriate parts of the project plan.

Managing Change

The following flowchart shows the steps involved in managing change in a project.



Hold Project Team Meetings

Why do it?

To periodically review with the team how the project is progressing so that concerns and opportunities can be unearthed, discussed, and resolved.

How do I do it?

1. **Prepare the variance reports on the project before the project team meeting.**
   - Variance reports represent a quantitative review of project progress. (See page 137 for instructions on how to calculate a variance.)
   - Usually the project leader prepares these reports and makes them available at each team meeting.

> *Team members who are leading subprojects (a type 3 project) should prepare variance reports for their subprojects and submit them to the project leader before each team meeting. Subproject teams also need to have their own team meetings.*

2. **Schedule periodic team meetings to review the status of the project.**
   - The frequency of team meetings will depend on the length and activity level of the project.
     - Short-lived projects, (those lasting six months or less), or projects that have a lot of ongoing activity, may require weekly or biweekly meetings.
     - Long-lived projects, (those longer than six months), or projects that have periods of little activity, may require monthly or bimonthly meetings.

Type 1 projects do not require separate team meetings since the team is already meeting regularly to do project work. A project review should be periodically added to the agenda for the regular team meetings.

Don't forget to invite the ad hoc members of the project team if any of the agenda items may affect them or their viewpoints are needed to resolve an issue.

Amy Lee holds bimonthly review meetings with the conference project team during the early part of the execution phase of the project. However, when the conference draws closer, the project team will meet weekly, or even daily if needed.

3. **Review the current status of the project.**

   - Team members should provide an update on the status of their assignments or the work in their subproject.
   - Team members should report their concerns or issues with the progress of the project. If any of these concerns cannot be immediately resolved, put them on the issues list.
   - The team should review the progress of the deliverables, and discuss any deviations from the plan.

- The project leader should compare the actuals to the plan, and the team should discuss the reasons for these variances.
- The team should revisit the risk rating for the project scope and the risk ratings for meeting the deadline dates to determine if they are still valid.
  - If the risk rating has dropped, then some or all of the countermeasures may no longer be needed.
  - If the risk rating has increased, then new countermeasures may need to be developed. Any changes to the countermeasures should be reflected in the schedule.
- The team should again estimate staff time and spending to make sure they don't exceed the limits, if there are limits. If the estimates do exceed the limits, develop some countermeasures.

4. **Review anticipated problems and requests for changes to the plan.**
   - If requests for changes to the project plan have been made, follow your team's process for managing change (see page 145 for a generic process).
   - Scan the environment for potential problems. Problems in the environment include organizational, regulatory, competitive, and technological changes that have an impact on the project.

Monitor the customer's situation to be sure nothing has changed. Customers often don't realize when a change can affect the project and may neglect to inform the team of changes that have occurred.

5. **Review and update the issues list.**
    - Review all the issues on the issues list, and note the resolution status for each issue.
    - Fully discuss any issues that the team has scheduled to be resolved by the meeting date. Review other issues quickly unless they are critical to the project.
    - If the team cannot resolve an issue or cannot resolve it by the required date, decide what further action is required and make the required changes to the issues list.
6. **Clear the "parking lot."**
    - Review the "parking lot" to be sure that all the issues, ideas, or questions that were brought up during the meeting have been addressed.
7. **Recognize accomplishments in the project.**
    - Balance the discussion of problems with a good dose of "a job well done." Everyone needs recognition now and then.

Hold Project Review Meetings

Why do it?

To periodically review the progress of the project with the sponsor and the customer. Any problems with—or ideas for—the project that the team, sponsor, or customer may have can be discussed, allowing the team to correct or improve the project process.

How do I do it?

1. **Schedule periodic sponsor and customer meetings to review the status of the project.**
   - Sometimes the customer is not available, and the team will not be able to invite the customer to review meetings.
   - Formal meetings with the sponsor and customer should be held on a monthly or quarterly basis, depending on the length of the project, the level of activity, or the degree of project risk. (Shorter projects should have monthly meetings, and longer ones quarterly meetings.)
   - Informal, informational meetings between the project leader and the sponsor or customer should be held as needed.

Check to see if the sponsor and customer review meetings can be combined. This will save time for everyone who should be involved in the meetings.

Amy Lee, the project leader for the 3-day conference, and Chris Wheeler, the project sponsor, have monthly review meetings. The project team is included in these meetings when a life-cycle stage for the conference is completed. For example, when the conference plan is ready to be issued at the end of stage 2 (Design or Plan), Amy, Chris, and the rest of the team will have a project review meeting.

The customers of the 3-day conference are not available to the project team and therefore are not involved in the review meetings. Customer issues are discussed during the team review and sponsor review meetings. Marketing represents the voice of the customer at these meetings.

2. **Review the current status of the project.**
    - The project leader should report on the progress of the deliverables.
    - The project leader should report on the status of the schedule, staff time, and budget; compare them to the project plan; and explain any variances.
    - The project leader should report on the current status of the risk for producing the deliverables and the risk of not meeting the schedule.

3. **Discuss changes in the environment and anticipated problems.**
    - Discuss changes in the environment, such as organizational, competitive, regulatory, and technical changes that could affect the project.
    - Review potential problems and requested or anticipated changes to the project plan. The customer and sponsor can help highlight things to look out for, suggest ways to avoid problems, and address or resolve problems.

4. **Review the issues list.**
    - The project leader should review the status of the issues that are external to the team.
    - The customer and sponsor do not need a review of the issues that will be resolved within the team, but they do need to be informed of the issues that may affect them or that require their assistance or intervention to be resolved.

> *Be sure the team has exhausted its options for resolving the problem before asking the sponsor or customer to get involved—unless a simple answer from one of them could resolve the issue quickly.*

5. **Solicit feedback from the sponsor and customer on ways to improve the project.**
    - Ask the sponsor and customer for feedback on how they perceive the project to be progressing. Solicit ideas from them for improving the project.

Chapter 6

How to Close Out the Project

When the customers of the project accept the final deliverables, it's time to close out the project. A project is closed out when the team members have received and evaluated all feedback on the project, and when the lessons learned from the project and recommendations for improvement have been shared with the organization. This helps future project teams duplicate the successes achieved and avoid the problems and failures experienced by the team.

When you need to:	Do this activity:	Page
Get feedback from the customers on the performance of the project.	Hold a Feedback Meeting with Customers	154
Analyze what happened in the project and develop ideas for improvement.	Hold a Team Meeting to Develop Lessons Learned	157
Review the project with the sponsor.	Hold a Project Review Meeting with the Sponsor	161
Document project results and recommendations for future projects.	Create the Close-out Report	162

Hold a Feedback Meeting with Customers

Why do it?

To solicit feedback and ideas for improvement from the customers of the project. By meeting with customers, the team gets to hear firsthand what they liked and did not like about the project. This helps the team decide how to do it better next time.

How do I do it?

1. **Review the commitments that were made to the project.**
   - Review with customers the executive summary of the project plan and any changes that were made to the plan.

Although this is a feedback meeting for the customers, the sponsor should be invited as well. The sponsor will then have the opportunity to provide additional feedback to the team.

2. **Solicit feedback on the customers' satisfaction with the project's deliverables.**
   - Find out how the deliverables have been performing for the customers. What has worked well for the customers, and what has not lived up to their expectations?

If the customers cannot attend the meeting, solicit their feedback before the meeting, and then evaluate and review that feedback during the meeting.

Listen to what the customers have to say without being defensive. The objective is to learn as much as possible from the customers, and the best way to do that is to listen openly and ask questions.

3. Ask the customers for feedback on the review and approval process.

- If the customers did not participate in the review and approval process, skip this step.
- Ask if the customers' expectations for the review process were met. What were they disappointed with? What were they satisfied with? What do the customers think the team should learn from the process? What ideas do the customers have for improvement?

4. Ask the customers for feedback on their perceptions of how effectively project resources were used.

- If the customers didn't "pay" for the project, either directly or indirectly (through internal charges), they probably weren't involved in how the resources of the project would be expended. In this case, skip this step.
- What do the customers think of the schedule, staff time, and budget? Were they realistic for the project? Is the value of the deliverables more than offset by the expenditures of time, effort, and money?
- Do the customers have suggestions for improving the way resources are used?

5. **Solicit the customers' feedback on the quality and frequency of the progress reports they received during the project.**

   - Were the customers satisfied with the reports produced by the project? Did they meet their needs? What ideas do they have for improvement?

6. **Ask the customers to evaluate the project process.**

   - What was their experience of the process? Were the objectives of the project clearly communicated to them? Was the project plan thorough? Were the customers' interactions with the project leader and project team positive? Did the process for managing change work well?
   - What would the customers have the team do differently next time? How could the project process be improved? What would the customers do differently next time?

The customers of the 3-day conference gave their feedback on the conference survey forms. Since they were not involved in the project process, they could provide feedback only on the deliverables. The sponsor was able to provide the remaining feedback.

Hold a Team Meeting to Develop Lessons Learned

Why do it?

To review the results from the project and to translate those results into lessons learned and recommendations for improvement. This allows the team to learn from their successes and their mistakes so that they can do a better job next time.

How do I do it?

1. **Review the objectives for the project.**
   - Review the project objectives as outlined in the charter (see Chapter 2).
   - Review the executive summary of the project plan and any changes that were made to the plan.

> *Make sure feedback is solicited from the sponsor and any other key stakeholders before the meeting starts. This information will be critical to evaluating the project and developing the lessons learned from the project.*

2. **Compare the real deliverables to those described in the plan (under project scope). Develop lessons learned.**
   - What was really created versus what was planned? Did the deliverables comply with the customers' and sponsor's acceptance criteria? Were the customers satisfied with the deliverables? Was the sponsor satisfied?
   - Was the risk of creating the deliverables assessed accurately? Were the assumptions correct? Were the countermeasures effective?

3. **Evaluate the review and approval process.**
   - What worked well in the review and approval process? What didn't work well? Were there enough reviews? Were there too many? Did the right people conduct the reviews?

4. **Review team membership.**
   - Were the right people on the team? Were the ad hoc members useful?

5. **Compare the actuals for the schedule, staff time, and budget to the project plan.**
   - The project leader should prepare and distribute the report on variances before the meeting. (Calculating a variance is described on page 137.)
   - Were there deviations from the project plan? Why did the deviations occur? Could they have been avoided?
   - Was the risk of not meeting the deadlines for the schedule accurate?

For type 3 projects, each subproject team should develop its own lessons learned and then share these with the project team. The project team should concentrate on lessons learned from the project as a whole.

6. **Review the status reports produced for the project.**
   - Were the reports produced on time? Were they helpful in monitoring the project? If not, why not?

7. **Evaluate the feedback information on the project process, and develop ideas for improvement.**
   - Evaluate the feedback from the sponsor and any other key stakeholders that were surveyed.

- Review the survey results, and discuss team members' perceptions of the process. What worked? What didn't work? How did the process for managing change perform? Were the team meetings effective?

Generic Feedback Survey Form

Feedback	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Description	**1**	**2**	**3**	**4**	**5**
Project objectives were clear.					
Project limits were realistic.					
Project team guidelines were followed.					
Project plan was thorough and accurate.					
Project plan was followed.					
Change management procedures were effective and useful.					
Sponsor and management support and inputs were helpful in meeting objectives.					

Note: Explain anything with a rating of 3 or less and any extraordinary successes.

8. Discuss the lessons learned on the project, and develop ideas for improvement.

- Discuss lessons learned for each area of the project—deliverables, reviews and approvals, team membership, and so on.
- What can be improved in each of these project areas so that future teams can avoid making the same mistakes and duplicate the same successes?

Hold a Project Review Meeting with the Sponsor

Why do it?

To review with the sponsor the results of the project and the team's preliminary ideas for improvement. By soliciting the final inputs from the sponsor before the close-out report is written, the team gets the benefit of the sponsor's ideas and creates more acceptance for the team's final recommendations.

How do I do it?

1. **Review the project plan.**
   - Review the executive summary of the project plan and any approved changes to the plan.
2. **Review the project results.**
   - Review the results for the deliverables, the review and approval process, the risks of creating the deliverables, team composition, the schedule, staff time, the budget, and project reports.
3. **Discuss with the sponsor the lessons the team learned from the project.**
   - Solicit additional lessons learned from the sponsor.
4. **Discuss ideas for improvement.**
   - Review the team's ideas for improvement. Solicit additional ideas for improvement from the sponsor.

Create the Close-out Report

Why do it?

To create a report for the organization that explains the performance of the project and the lessons learned, and makes recommendations to senior management for improvements to the project management process. By writing a close-out report, the team shares its project experience with management and with future teams so that the lessons learned will be passed onto others.

How do I do it?

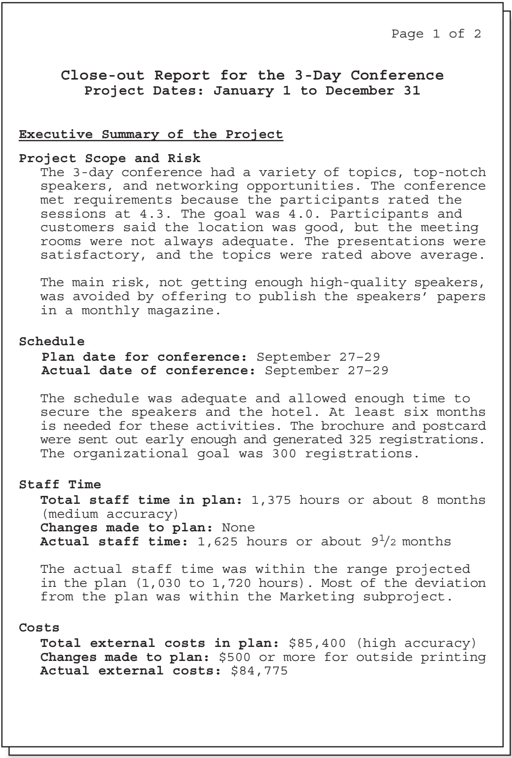
1. **Create an executive summary for the close-out report.**
   - Divide the executive summary into the following sections:
     - Project Scope and Risk
     - Schedule
     - Staff Time
     - Costs
     - Lessons Learned
   - Within each section, document the following:
     - The original plan objective, deadline, or limit
     - Any changes made to the plan
     - The actual results of the project, that is, actuals for staff time or budget, actual final deliverable dates, the customer evaluation of the final deliverables
     - What was learned related to that section and what should be done differently next time (in the lessons learned section, summarize the overall lessons learned from the project and recommendations for improvement)

2. **Attach reports on project variances; feedback from the customer, sponsor, and team; lessons learned; and recommendations for future projects, if available.**

   - Record the feedback received from the customer, sponsor, and team members. Include any results from review meetings.

3. **Distribute the report and archive it.**

   - Provide a copy of the report to the sponsor, to regular and ad hoc team members, and to other teams that might benefit from the lessons learned.
   - If a program office or steering group exists that oversees projects, send them a copy of the report as well. It will serve as a source of ideas for improvement and as data for possible statistical analysis.



Page 1 of 2

Close-out Report for the 3-Day Conference
Project Dates: January 1 to December 31

Executive Summary of the Project

Project Scope and Risk

The 3-day conference had a variety of topics, top-notch speakers, and networking opportunities. The conference met requirements because the participants rated the sessions at 4.3. The goal was 4.0. Participants and customers said the location was good, but the meeting rooms were not always adequate. The presentations were satisfactory, and the topics were rated above average.

The main risk, not getting enough high-quality speakers, was avoided by offering to publish the speakers' papers in a monthly magazine.

Schedule

Plan date for conference: September 27–29
Actual date of conference: September 27–29

The schedule was adequate and allowed enough time to secure the speakers and the hotel. At least six months is needed for these activities. The brochure and postcard were sent out early enough and generated 325 registrations. The organizational goal was 300 registrations.

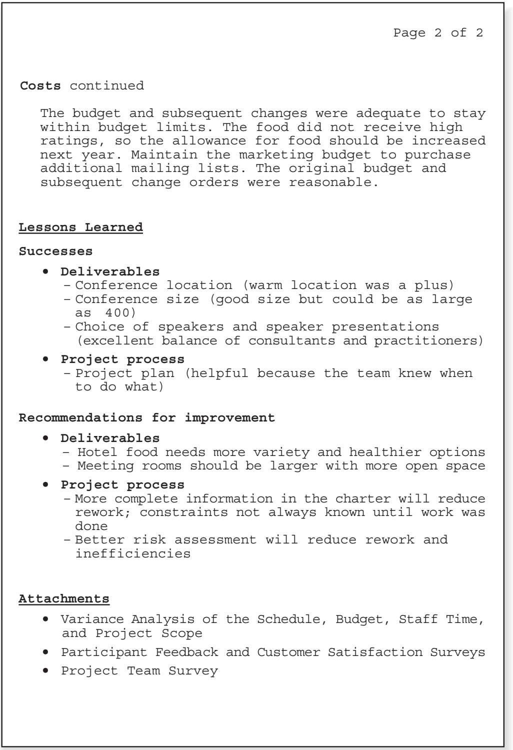
Staff Time

Total staff time in plan: 1,375 hours or about 8 months (medium accuracy)
Changes made to plan: None
Actual staff time: 1,625 hours or about $9\frac{1}{2}$ months

The actual staff time was within the range projected in the plan (1,030 to 1,720 hours). Most of the deviation from the plan was within the Marketing subproject.

Costs

Total external costs in plan: $85,400 (high accuracy)
Changes made to plan: $500 or more for outside printing
Actual external costs: $84,775



Page 2 of 2

Costs continued

The budget and subsequent changes were adequate to stay within budget limits. The food did not receive high ratings, so the allowance for food should be increased next year. Maintain the marketing budget to purchase additional mailing lists. The original budget and subsequent change orders were reasonable.

Lessons Learned

Successes

- **Deliverables**
  - Conference location (warm location was a plus)
  - Conference size (good size but could be as large as 400)
  - Choice of speakers and speaker presentations (excellent balance of consultants and practitioners)
- **Project process**
  - Project plan (helpful because the team knew when to do what)

Recommendations for improvement

- **Deliverables**
  - Hotel food needs more variety and healthier options
  - Meeting rooms should be larger with more open space
- **Project process**
  - More complete information in the charter will reduce rework; constraints not always known until work was done
  - Better risk assessment will reduce rework and inefficiencies

Attachments

- Variance Analysis of the Schedule, Budget, Staff Time, and Project Scope
- Participant Feedback and Customer Satisfaction Surveys
- Project Team Survey

Recommended Activities for the Project Types

The table below lists the project types described in this book (type 1, 2 and 3) and the specific activities that are *recommended* for each project type. Keep in mind that each project is different and that your project team should judge the appropriateness of completing a specific activity, whether it has been recommended or not.

This table, while intended for all project types, will be the most useful for type 1 project teams since they will be completing the fewest activities and may want to quickly review just these activities. Refer to page 7 to see the distinctions between project types.

Project Activities by Chapter	Page	Type 1	Type 2	Type 3
2 Create a Charter (sponsor does this)	11–42	ALL	ALL	ALL
3 Work Together as a Team	43–50	ALL	ALL	ALL
4 Create a Project Plan (team does this)	51–134			
Expand on the project scope description	54–55	✔	✔	✔
Determine interim deliverables	56–60	✔	✔	✔
Determine processes/projects	61–63	✔	✔	✔
Create subprojects and assign work	64–68		✔	✔
Complete reviews/ approvals list	70–72	✔	✔	✔

Project Activities by Chapter	Page	Type 1	Type 2	Type 3
4 **Create a Project Plan** continued				
Assess the risk	74–77	✔	✔	✔
Complete status reports list	79–81		✔	✔
Review team membership	83–87	✔	✔	✔
Construct milestone schedule	89–93	✔	✔	✔
Create deliverables schedule	94–101		✔	✔
Create activity schedule	102–109		✔	✔
Draw Gantt chart	110–111			✔
Estimate staff time	113–117	✔	✔	✔
Create staffing forecast	118–120			✔
Estimate costs	122–127		✔	✔
Create spending forecast	128–129			✔
Assemble the plan	131–134	✔	✔	✔
5 **Do the Project** (team does this)	135–152	ALL	ALL	ALL
6 **Close Out the Project** (sponsor, customers, and team do this)	153–165	ALL	ALL	ALL

Tool Application Chart

The chart below summarizes how project teams typically use tools in their projects. The last column on the right (MJII page) refers to the pages in the *Memory Jogger™ II* that describe the tool. *The Memory Jogger II: A Pocket Guide of Tools for Continuous Improvement and Effective Planning* is also published by GOAL/QPC.

Tool	Example on page	Use it to . . .	MJII page
Activity Network Diagram (AND)	N/A	• Identify and calculate the critical path • Determine how to shorten a schedule that does not meet deadlines	3–11
Affinity Diagram	N/A	• Identify customer requirements when they are undefined • Clarify any issue that is confusing or overwhelming • Achieve breakthroughs in the development of deliverables	12–18
Brainstorming	46, 75	• Generate ideas for an Affinity Diagram • Generate ideas for project deliverables (to use in a Tree Diagram)	19–22
Flowchart	10, 145	• Document a process that will be improved or created as part of the project	56–62
Gantt Chart	111	• Display the project schedule at a glance	9

Tool	Example on page	Use it to . . .	MJII page
Matrix Diagram	5	• Record team responsibilities	85–90
	23	• Document reviews and approvals	
	138	• Display variances from the project plan	
	143	• Display the issues list and change requests	
	159	• Document and display customer feedback	
Prioritization Matrices	N/A	• Define customer requirements • Select countermeasures to reduce risk • Put objectivity into the decision-making process	105–114
Process Decision Program Chart (PDPC)	N/A	• Assess project risk and create countermeasures • Anticipate and prevent potential problems	160–162
Tree Diagram	65	• Create the breakdown of the project into subprojects and subproject deliverables • Refine customer requirements	156–159

About this Book

The method described in this book was developed by the authors to help simplify the process of moving a project successfully from concept to completion. It is consistent with industry standard approaches such as PMBOK (Project Management Body of Knowledge), with an emphasis on participation, empowerment, individual accountability, and bottom-line results. It utilizes tools and concepts from continuous process improvement and applies them to making project management accessible to anyone working on a project.

About the Authors

Karen Tate, PMP® is founder of The Griffin Tate Group, Inc., a Global Charter Registered Education Provider of PMI®. Griffin Tate provides project management training and consulting for everyone in an organization including project teams, project managers, project sponsors and senior level managers. She is a project management professional (PMP®), certified by PMI®. She has over 20 years of project management experience — as a project manager, project sponsor, program manager, project trainer, project facilitator, and project consultant.

Paula Martin also has extensive project management experience. Before becoming a consultant, she directed American Cyanamid's U.S. new product development efforts, overseeing hundreds of projects and project teams. Paula has also consulted extensively on the subject of accountability and she is author of *The Buck Stops Here: Accountability and the Empowered Manager*.

Index