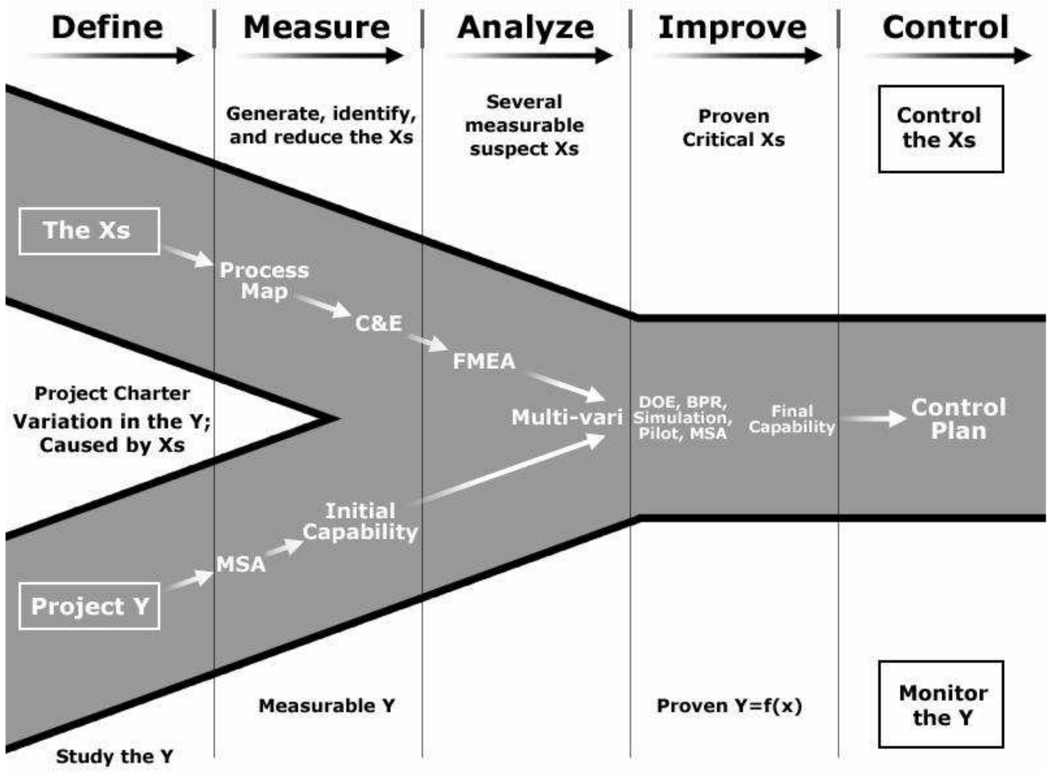
3M Six Sigma
DMAIC Guide Book

The Roadmap



How to Use the *3M Six Sigma DMAIC Guide Book*

How do I make use of this *3M Six Sigma DMAIC Guide Book*?
The *3M Six Sigma DMAIC Guide Book* has been designed for your use during class and as a reference tool while working on your projects.

How is the *3M Six Sigma DMAIC Guide Book* arranged?
Arranged around the DMAIC roadmap, the *3M Six Sigma DMAIC Guide Book* has a separate section for each of the DMAIC phases. The appropriate tools are highlighted within the sections. A Table of Contents is located at the front of the book to guide you to specific pages.

What are key areas in the *3M Six Sigma DMAIC Guide Book*?
The *3M Six Sigma DMAIC Guide Book* contains the following areas within each of the tools:

Steps and ***Roadmaps*** highlight the steps needed to complete a tool.

Hints are recommendations on how to effectively use the tool.

Pitfalls are cautionary notes on potential difficulties and problems that can be encountered using the tool.

Checklists are questions to review to ensure the key items have been covered in the tool and/or DMAIC phase.

Lessons Learned is the area where you can make your own notes.

The ***Appendix*** contains a listing of frequently used terms and additional tools and resources to help with DMAIC projects.

How can I order more copies or see an electronic copy of the *3M Six Sigma DMAIC Guide Book*?
To order more copies (or to view an electronic version) of the Six Sigma DMAIC Guidebook, go to the Lean Six Sigma Work Center on 3M Source and look under Lean Six Sigma Services > Learning Resources > Methodologies > DMAIC (Six Sigma).

What Resources Are Available to You?

Multiple resources exist to help you on your project (internal 3M use only). They include:

- Your Black Belt and Master Black Belt
- Your Division Coach and Green Belt Coach
- Lean Six Sigma Black Belt Coaches (3M Lean Six Sigma Operations Department)
- 3M Lean Six Sigma Hotline: (651) 736-7446
- eMail 3M Lean Six Sigma Hotline: LeanSixSigmaOperations
- 3M Lean Six Sigma Work Center: http://3msource.mmm.com/wps/myportal/3M/en_US/Lean_Six_Sigma/Work_Center_Home/
- Minitab and BP Chart (search for Minitab or BPChart in Tool Selector): http://3msource.mmm.com/wps/myportal/3M/en_US/Lean_Six_Sigma/Work_Tools/SoftwareTools
- Minitab support: http://www.minitab.com
- Global Project System (GPS): http://intra3.mmm.com/globalprojectsystem ; (GPS Helpline = (651) 575-6042) ; email = GPSHelpline
- Other: www.isixsigma.com, mathworld.wolfram.com, www.statsoft.com/textbook/stathome.html

Table of Contents

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I. DMAIC Process Overview

DMAIC Purpose:

- Identify, quantify and eliminate sources of variation
- Improve and sustain performance with well executed control plans
- Growth!

DMAIC Goals:

- Breakthroughs achieved in customer satisfaction, growth, cost (productivity), and cash (working capital)

A. DMAIC Methodology

Six Sigma is a process improvement and business strategy that is built on 3M's history of continuous improvement. The DMAIC methodology is a five phase approach to improving existing processes. The five phases are: Define, Measure, Analyze, Improve, Control.

Define: What is happening now?

Purpose: Develop a fully defined project by defining and understanding the process to improve and developing a clear statement of the team's goal. This is documented in the form of a project charter, which answers these and other questions:

- "What is the **process**?" – series of steps and activities
- "What is the **scope** of this Project?" – boundaries; what is included and excluded
- "How is the project linked to the **business winning strategies**?" – linkage to the business needs
- "What is the process **defect**?" – problems; how the process fails to meet customer needs
- "What is **causing** the pain?"
- "What will be **measured** and how?" – once we make improvements, what will be measured to demonstrate the problems are improved

Measure: What is the root cause of the defects?

Purpose: Define the current process and establish metrics. Focus the improvement effort by gathering information on the current situation.

1. Map the process, identifying the inputs (X's) and outputs (Y's) of each step.
2. Utilize a Cause & Effects Matrix (C&E) to rate inputs (X's) against the key project outputs (Y's)
3. Complete a Measurement System Analysis (MSA) to determine whether the measurement system for the Project Y data is "good enough."
4. Gather data to establish baseline performance of the process (project Y data).

Analyze: How can I use data to understand the root cause?

Purpose: Learn about the relationships between the inputs (X's) and outputs (Y's) and identify potential sources of process variability. Reduce the number of inputs (X's) to an important few and verify this with data.

1. Examine the root cause of the important inputs (X's) from the Cause & Effects (C&E) matrix with the Failure Modes & Effects Analysis (FMEA).
2. Gather Multi-Vari data on the process (using surveys, historical data or process observation).
3. Use graphs and statistical analysis to confirm or reject the Critical Inputs (X's) identified in the Cause & Effects Matrix (C&E) and Failure Modes & Effects Analysis (FMEA).

Improve: What improvements can we put into place to eliminate the root cause?

Purpose: Verify the critical inputs (X's) and/or proposed solutions.
Identify and test possible improvements to verify the effect of each of the suspected inputs (X's) or to verify the efficacy of a proposed solution.

Control: What controls will ensure the root cause is permanently resolved?

Purpose: Develop a plan to control the critical inputs (X's) and monitor the process performance. Develop procedures and/or implement data monitoring to standardize any changes to the process and to ensure the process continues to perform at the desired level. Maintain the gains!

Key Terms:

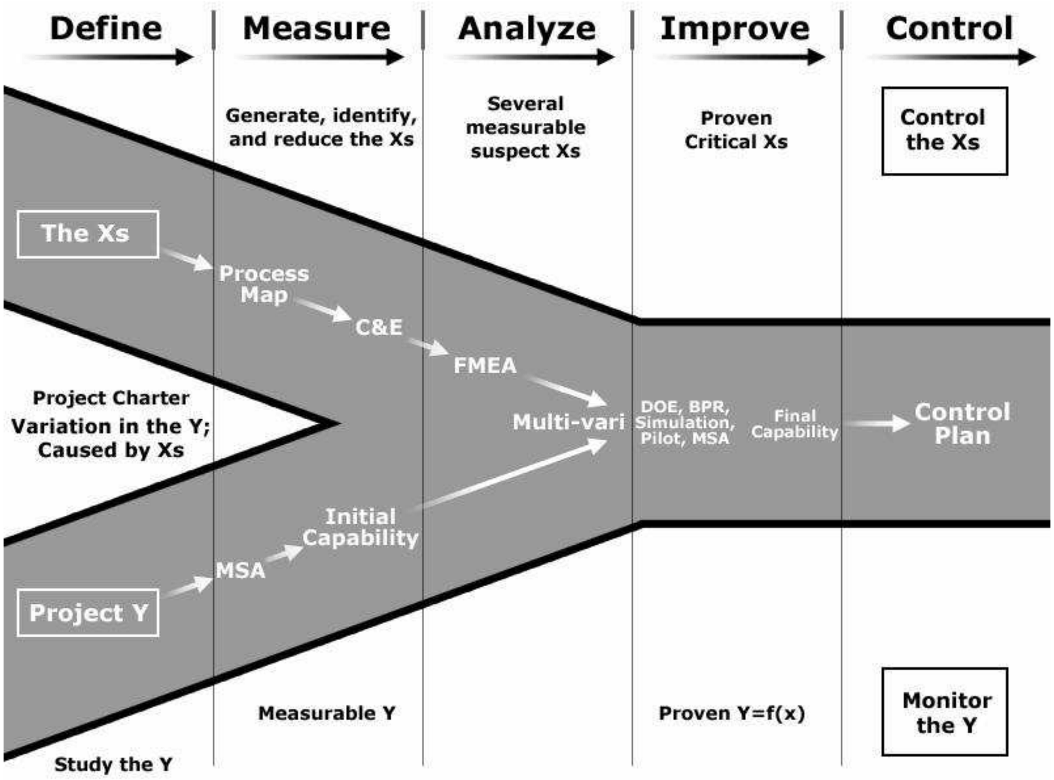
- **Y's – Outputs of Process (Noun)**
  - Process output variables or customer requirements
  - Associated with process performance/defect measures
  - Examples: % Lines-on-Time, % Deductions, % Sales by Store, Number rolls produced on line
- **X's – Inputs to Process (Noun)**
  - Process input variables
  - Associated with the sources of variation
  - Examples: Marketing programs, shelf placement of product, type of product, chemical mixture, manufacturing line

$$\boxed{y = f(x_1, x_2, \ldots, x_k)}$$

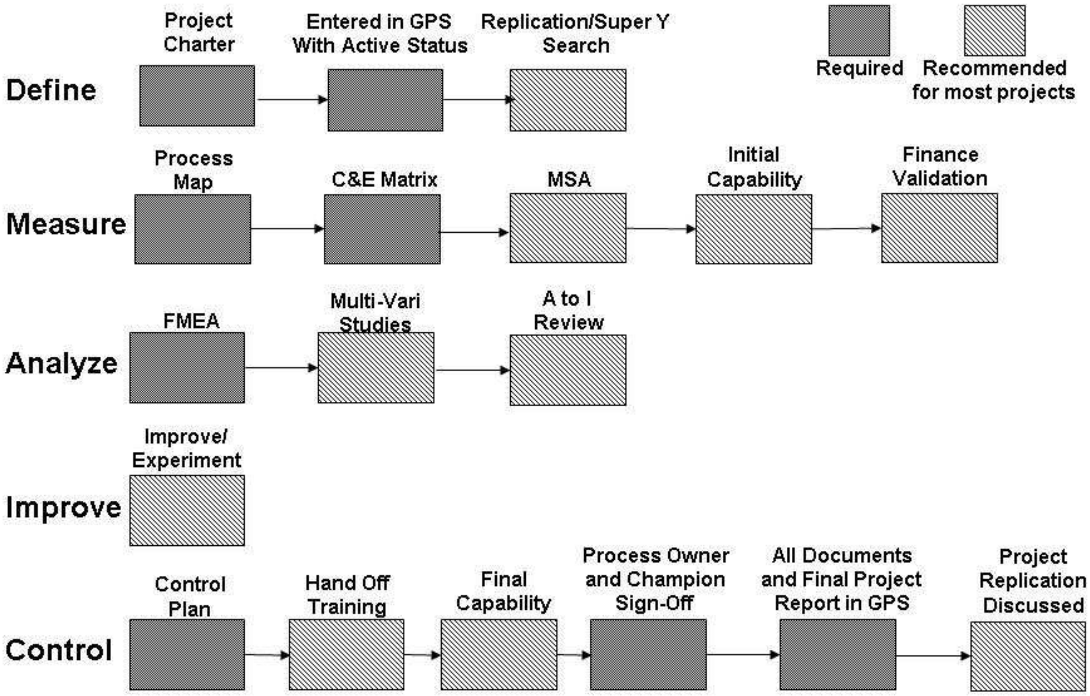
B. DMAIC Roadmap & Project Tracking Charts

The following charts show the flow and connectivity of the DMAIC tools.

The Roadmap



Project Tracking



C. Roles and Responsibilities

Champion

- Sets and maintains broad goals for improvement projects in area of responsibility
- Owns the hopper process and their portion of the business Y tree and charters projects
- Coaches and approves changes, if needed, in direction or scope of a project
- Finds (and negotiates) resources for projects
- Represents the team to the Leadership group and serves as its advocate (able to discuss current status of the projects they champion)
- Helps smooth out issues and overlaps that arise between teams or with people outside the team
- Works with Process Owners to ensure a smooth handoff at the conclusion of the project (ensures that control plan is effective in improving Y)
- Responsible for functional project hopper
- Regular reviews with Process Owner on key process inputs and outputs
- Uses DMAIC tools in everyday problem solving
- Responsible for team recognition

Process Owner

- Maximizes high level process performance
- Launches and sponsors improvement efforts (fills hopper with ideas and writes charters)
- Tracks financial benefit of project (during the 12 month tracking period)
- Understands key process inputs and outputs and their relationship to other processes
- Key driver to achieve Six Sigma levels of quality, efficiency and flexibility for this process
- Uses DMAIC tools in everyday problem solving
- Participates on GB/BB teams
    - Helps create/maintain control plan documentation and assigns responsibility for on-going use of control plan
    - Helps train process team in use of control plan
    - Measures and monitors (SPC) “Critical X’s” and sustains effectiveness of control plan

Team Member

- Participates with project leader (GB or BB)
- Provides expertise on the process being addressed
- Performs action items and tasks as identified
- Uses DMAIC tools in everyday problem solving
- Subject matter expert (SME)

Green Belt (GB)

- Leads and/or participates on Six Sigma project teams
- Identifies project opportunities within their organization
- Know and applies Six Sigma methodologies and tools appropriately

Black Belt (BB)

- Proficient in Six Sigma tools and their application
- Leads/supports high impact projects to bottom line full-time
- Directly supports MBB's culture change activities – communicates Six Sigma methodology and tools
- Shares best practices
- Mentors and coaches Green Belts to optimize functioning of Six Sigma teams operating in organization
- Facilitates, communicates, and teaches
- Looks for applicability of tools and methods to areas outside of current focus
- Supports Process Owners and Champions in hopper processes (as assigned)

Master Black Belt (MBB)

- Owns Six Sigma deployment plan and project results for their organization
- Ensures rigor in Six Sigma execution
- Responsible for BB certification
- Owns the Six Sigma project hopper and processes for the organization
- Supervisor for DMAIC BB's; may be supervisor for DFSS BB's
- Influences General Manager / Managing Director and Champions to support organizational engagement
- Leads culture change – communicates Six Sigma methodology and tools
- Leverages best practices
- Supports Champions in managing project hoppers and project prioritization; Checks projects for alignment with division / subsidiary / staff goals
- Ensures that project progress check, gate review, and closing processes meet corporate requirements and meet division needs
- Develops BB talent and builds organizational capability through BB's and GB's
- Supports timely Six Sigma project completion
- Communicates, teaches, and coaches

Coach

- Some businesses have coaches who support the GB's within their divisions. Other businesses use only the Six Sigma Operation coaches who primarily coach the BB's.
- Trains Green Belts with help from BBs and MBB
- Coaches BBs and GBs in proper use of tools for project success
- Is a consulting resource for project teams

Finance

- Establishes common measures of project success
- Signs off on calculation of project estimates and results
- Confirms the Project Y objective as defined by the BB is appropriate and will result in "hard" savings
- Provides ideas into the project hopper
- Works with MBB, Champions, Managing Director / General Manager to quantify projects
- Identifies risks and opportunities associated with projects

II. Define

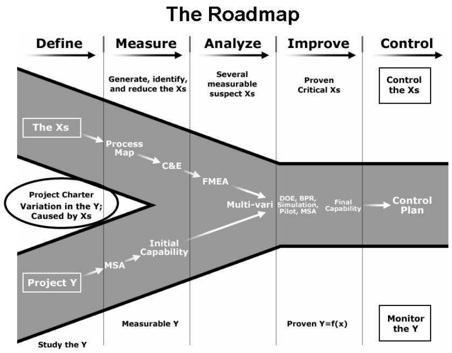
Define Phase Purpose:

- Define and understand the process to be improved and to develop a clear statement of the team's goal
- To develop a fully defined project with a working charter

Define Phase Goals:

- Project selection driven through business strategy and business critical Y's
- Voice of customer incorporated into metrics
- Project objectives clearly defined
- Project appropriately scoped

A. Project Charter



Project Charter Purpose:

- Initiate a Six Sigma project with clear definition of scope and project variables
- Clarify what is expected of the team
- Keep the team focused
- Keep the team aligned with organizational priorities

Project Charter Goals:

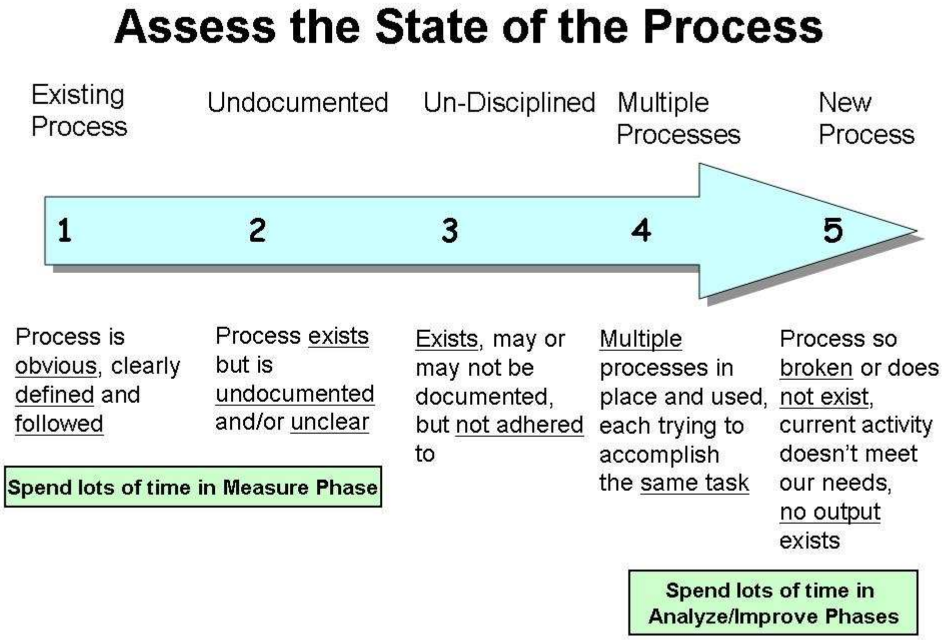
- Clearly defined project objectives

Questions Used To Identify Good Projects

- What is the most important thing(s) on which I am working? Where is the pain? (Project created by GB)
- Which of these things are critical to our business achieving our strategic goals? (Project created by GB or project assigned to GB)
- What aspect, if changed, would allow me to complete my work in less time, with a better result, and make my life easier?
- What process contains this defect? Is the process itself defective?

Project Evaluation Tool

Compare the project process to the chart below. The further to the right the process matches, the more difficult the project could be and the more help will be needed from the BB and/or coach.



Key Elements of a Project Charter

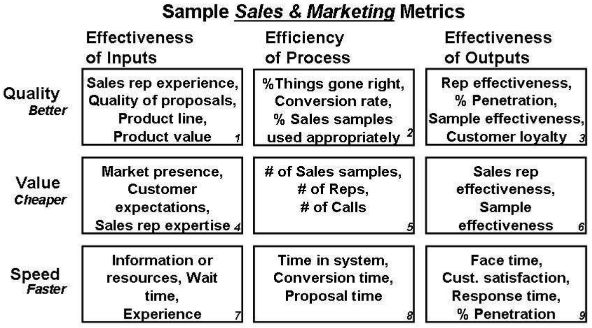
1. **Project Y** – What is the key measure the project is focused on?
   a. Most important section of the charter! Must be measurable (physical output of process)!
   b. Key process output that will address the defect and improve the Business Critical Y
   c. Helps define project **scope**
   d. Used in virtually every Six Sigma tool in DMAIC process
   e. Describe what going to accomplish in project
   f. Include a statement of "Improve/increase/reduce ***from*** baseline ***to*** goal without harming *counterbalance* by *timeframe*"
      - **Baseline** – Actual performance of process that is to be improved
      - **Goal** – 70% of the gap between entitlement and baseline (should be a "stretch" goal)
   g. Avoid dollars as project Y (rather source of savings)
   h. Do not write solution as project Y
   i. Possible measurements and evaluation criteria include:
      - **COPQ (Cost of poor quality)** – Measurement of documented costs of mistakes or error, such as complaint costs, rework costs, waste, etc.
      - **C_{pk} (Process Capability Index)** – Measurement of a process variable's short term performance. Requires ranges to be defined (preferably by the customer). C_{pk}'s less than 1 indicate room for improvement. C_{pk}'s greater than 1.33 indicate only limited room for improvement. (See "Capability" section for more information.)
      - **P_{pk} (Process Performance Index)** – Measurement of process variable's long term performance. Requires ranges to be defined (preferably by the customer). P_{pk}'s less than 1 indicate room for improvement. P_{pk}'s greater than 1.33 indicate only limited room for improvement. P_{pk}'s greater than 1.5 fulfill Six Sigma requirements. (See "Capability" section for more information.)
      - **DPU (Defect per unit)** – General measurement for the number of errors per unit. "Error" is defined as unwanted events (e.g. non-answered telephone calls per day, etc).
      - **RTY (Rolled throughput yield)** – Measurement of the process's actual yield based on the individual process steps.

2. **Project Y Entitlement** – What is the best possible performance that has been recently observed or was observed in a benchmarking study?
   a. Provides a performance level for which to aim – used to establish realistic stretch goals
   b. Defines what's possible
   c. Can come from:
      - Best observed performance over a "short" period of time
      - Observed by benchmarking
      - Performance specified by equipment manufacturer
      - Predicted by engineering & scientific fundamentals

3. **Process Defect** – What is the pain we are experiencing that we want to improve?
   a. If not described correctly and focused, the project team will not be set up for success
   b. Description should be clear, concise, definitive and have measurable outputs
   c. Timing should be included to drive need for completion

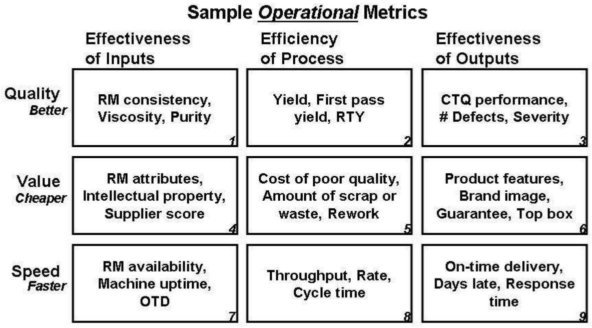
4. **Scope/Boundaries** – What are the specific limits or confines of the project? What is included/excluded?
   a. Defines the project's focus and "boundaries" for the team
   b. "In frame-out of frame" criteria (see Appendix), such as:
      - Process steps included
      - Product lines
      - Customer segment
      - Site/location
      - Technology
      - Project budget

5. **Process Definition** – What are the series of steps or activities where the pain or opportunity exists?
    a. Written identification of the process to be improved
    b. Helps maintain the proper focus
6. **Business Critical Y** – What is the opportunity as it relates to strategic business goals?
    a. Project should show alignment with business team, Division, and Corporate goal trees
    b. Set by MBB in partnership with business leaders as high level goal for division, not project specific
7. **Project Metrics** – What do you need to measure and monitor to determine the success of the project?
    a. **Primary Y** – What is the main thing we want to improve? (Very similar to Project Y – could be the same metric)
    b. **Secondary Y** – What is something else we are interested in improving? (Optional)
    c. **Counter-balancing Y** – What don't we want to negatively impact while improving the Primary Y?
8. **Corporate Critical Y** – Is the project a Cash, Cost or Growth?
9. **Super Y** – Which of the corporately defined sub-grouping of projects is this project related to? (See the Global Project System (GPS) website for current Super Y's.)
10. **Business Impact** – What is the financial impact to the company?
    a. Clearly defined, mathematical (if possible) description of how to calculate benefits impact ($$$)
    b. Must be accepted, supported and validated by the Controller / Finance community
    c. If not defined well in the beginning of the project, you may struggle at the end to determine the financial impact



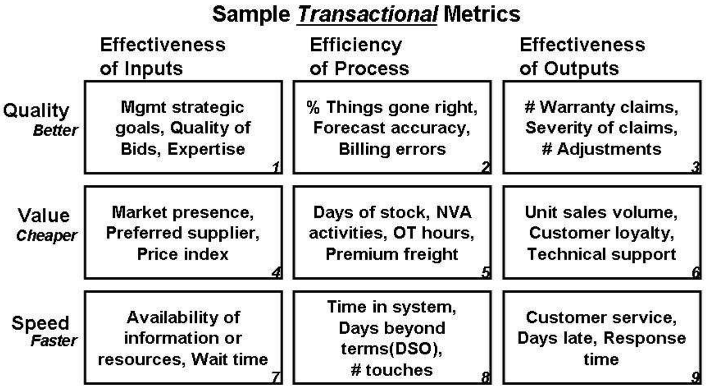
Sample *Sales & Marketing* Metrics

	Effectiveness of Inputs	Efficiency of Process	Effectiveness of Outputs
Quality *Better*	Sales rep experience, Quality of proposals, Product line, Product value 1	%Things gone right, Conversion rate, % Sales samples used appropriately 2	Rep effectiveness, % Penetration, Sample effectiveness, Customer loyalty 3
Value *Cheaper*	Market presence, Customer expectations, Sales rep expertise 4	# of Sales samples, # of Reps, # of Calls 5	Sales rep effectiveness, Sample effectiveness 6
Speed *Faster*	Information or resources, Wait time, Experience 7	Time in system, Conversion time, Proposal time 8	Face time, Cust. satisfaction, Response time, % Penetration 9



Sample *Operational* Metrics

	Effectiveness of Inputs	Efficiency of Process	Effectiveness of Outputs
Quality *Better*	RM consistency, Viscosity, Purity 1	Yield, First pass yield, RTY 2	CTQ performance, # Defects, Severity 3
Value *Cheaper*	RM attributes, Intellectual property, Supplier score 4	Cost of poor quality, Amount of scrap or waste, Rework 5	Product features, Brand image, Guarantee, Top box 6
Speed *Faster*	RM availability, Machine uptime, OTD 7	Throughput, Rate, Cycle time 8	On-time delivery, Days late, Response time 9



Sample *Transactional* Metrics

	Effectiveness of Inputs	Efficiency of Process	Effectiveness of Outputs
Quality *Better*	Mgmt strategic goals, Quality of Bids, Expertise 1	% Things gone right, Forecast accuracy, Billing errors 2	# Warranty claims, Severity of claims, # Adjustments 3
Value *Cheaper*	Market presence, Preferred supplier, Price index 4	Days of stock, NVA activities, OT hours, Premium freight 5	Unit sales volume, Customer loyalty, Technical support 6
Speed *Faster*	Availability of information or resources, Wait time 7	Time in system, Days beyond terms(DSO), # touches 8	Customer service, Days late, Response time 9

Project Chartering Tips

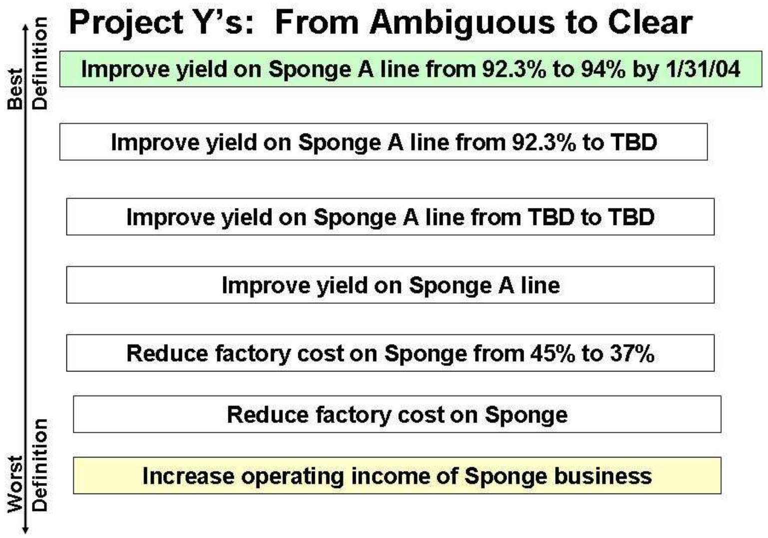
- Tackle processes that are within your team's sphere of influence - activities/processes that **they** do and that **they** own
- Focus on activities that have pain points; things important in your team's day-to-day jobs. For example - NOT: "Implement a new product tracking database."(one-time task), but rather: "Improve the process by which new product team members gather and submit new product information" (process needing improvement)
- Review other projects that share your project's Super Y. Can you replicate another project?
- Include project goals for all measurements – including counterbalances if identified.
- Use In-Frame/Out-of-Frame (see Appendix) to identify/validate scope of process
- Use the Stakeholder Analysis (see Appendix) to identify key players in the project and to find the right champion.
- Review the charter with your Champion, Process Owner, BB, and team to ensure everyone is in agreement.

Common Project Chartering Pitfalls

- Rushing through Project Charter instead of taking time to do it well
- **Too large** or broad of a **scope**. Micro focused – too narrow to have impact. Try to find a "bite sized" project – one that can be accomplished in 4-6 months.
- Having **too many metrics** ("boiling the ocean") or a **vague** Project Y. Try to identify the key issues to address for clear team direction.
- Process Owner or BB or Champion **missing** from Project Charter
- Having a **solution** in mind. Do not force your desired solution for the problem into the charter. Be open to all potential solutions.
- Having a **task oriented** rather than process improvement project. Ideally the project should improve an entire ongoing process rather than standing alone as a one-time task to be accomplished.
- Having **dollars** in Project Y. Dollars describe the financial benefit of the project. Instead look at the process that will be improved to gain the financial benefit.
- **Not** having a **measurable** Y – if you can't measure it, you won't know if you've improved it. Work with your coach to determine how to measure the Y before you dig into the project.

Project Y Evaluation Tool

Compare the Project Y to this chart. The closer the Project Y definition is to the top, the clearer the project focus. The closer the Project Y definition to the bottom, the more work needed to create clarity.



Project Charter Quality Scorecard Tool

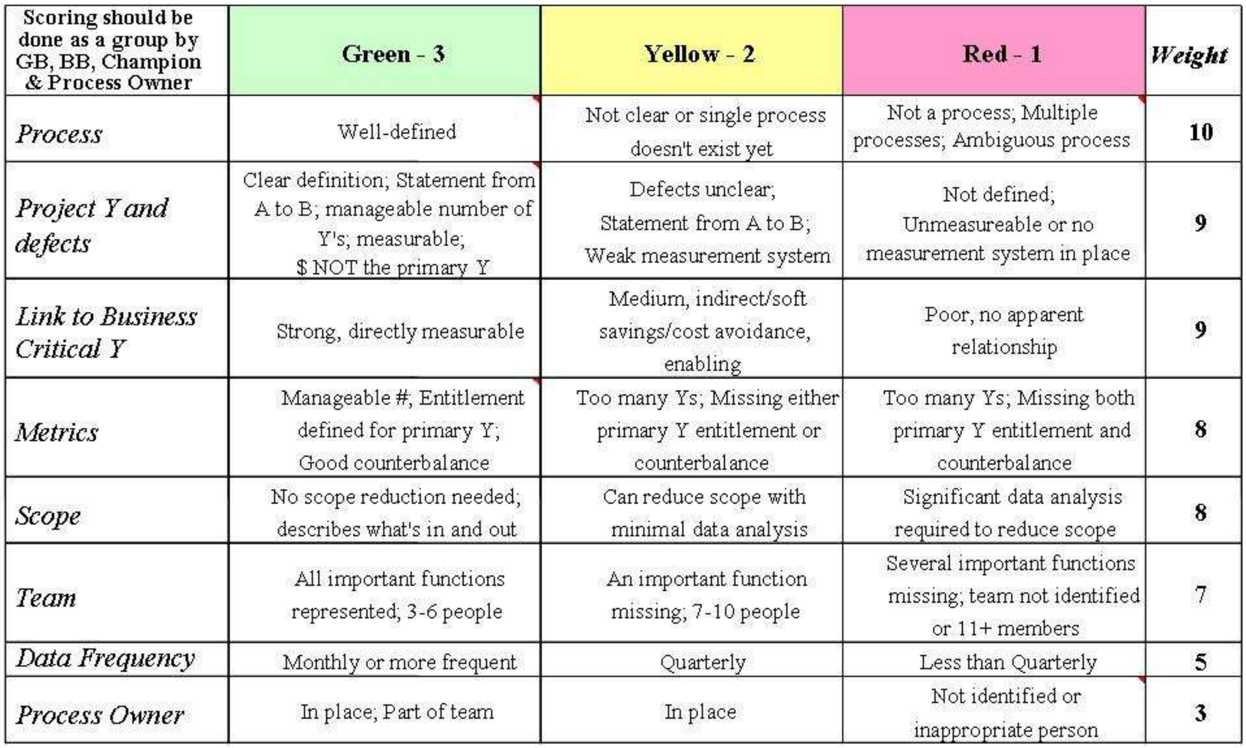
The scorecard below can be used to score the strength of a project charter. The efficiency of the project depends on a clearly written, well thought out charter.

Step 1: Team and team leader should review their project charter fields against the lines in the table below. For each key area listed, **rate** the project charter:

- Green: 3 points
- Yellow: 2 points
- Red: 1 point

Step 2: Multiply the rated score for each line times the weight listed at the end of each line.
Step 3: Sum all the multiplied scores/weights.
Step 4: **Compare** project charter score against the guidelines.

- The higher the score, the better the charter. Maximum possible score on the charter is 177. While many charters have the potential to reach 177, not all will.
- Most good charters should be able to achieve a score of 145 or higher.
- A yellow rating for each attribute would lead to a score of 118.
- Any charters scoring below 118, or any areas receiving a red (1) score should be reviewed and/or discussed with a Black Belt, champion or coach. The project could be a candidate for Business Process Redesign (BPR).



Scoring should be done as a group by GB, BB, Champion & Process Owner	Green - 3	Yellow - 2	Red - 1	*Weight*
Process	Well-defined	Not clear or single process doesn't exist yet	Not a process; Multiple processes; Ambiguous process	**10**
Project Y and defects	Clear definition; Statement from A to B; manageable number of Y's; measurable; $ NOT the primary Y	Defects unclear; Statement from A to B; Weak measurement system	Not defined; Unmeasureable or no measurement system in place	**9**
Link to Business Critical Y	Strong, directly measurable	Medium, indirect/soft savings/cost avoidance, enabling	Poor, no apparent relationship	**9**
Metrics	Manageable #; Entitlement defined for primary Y; Good counterbalance	Too many Ys; Missing either primary Y entitlement or counterbalance	Too many Ys; Missing both primary Y entitlement and counterbalance	**8**
Scope	No scope reduction needed; describes what's in and out	Can reduce scope with minimal data analysis	Significant data analysis required to reduce scope	**8**
Team	All important functions represented; 3-6 people	An important function missing; 7-10 people	Several important functions missing; team not identified or 11+ members	**7**
Data Frequency	Monthly or more frequent	Quarterly	Less than Quarterly	**5**
Process Owner	In place; Part of team	In place	Not identified or inappropriate person	**3**

Task-Oriented Projects

Some projects are more task-oriented than process improvement oriented.

Project Examples:
Raw material substitution, source of supply change, change of product in customer planogram

Project Y Examples:

- Identify 3-4 "Critical to Quality" (CTQ) characteristics as your key metrics; these are the product parameters that you don't want to screw up.
- Project Y might be written as "Replace _____ with______, while maintaining performance on X, Y, Z."
  - Might list dollars as secondary or counterbalancing metrics – but preference is to not include dollars.
  - In writing these types of Project Y's, key question to ask is "Which process are we working on?" This will focus use of tools in a useful way.
- Examples:
  - *"Replace raw material X with raw material Y, while maintaining current performance on flexibility and stretch"*
  - *"Move product A from manufacturing site 1 to manufacturing site 2, while maintaining current performance on adhesion"*

Use of Tools:

- Type 1: Decision has already been made to do a **particular task** and **solution** (raw material, new source of supply, etc) has been identified.
  - Do process map on part of manufacturing process that **change will affect**.
    - Outputs (Y's) will be key product characteristics listed as your primary metrics
    - Cost may be secondary Y (and benefit)
  - These projects typically have **two initial capabilities**
    - One from **old** process and one from first effort at using **new** process/raw material
    - New capability should **match old process** capability
  - Example:
    - *Know what raw material will be substituted, or a second source of supply has been identified. Map the part of manufacturing process where the raw material change will have impact.*
- Type 2: **Need** for a particular task has been **identified**, but specific **solution** has **not** yet been **identified**. Should be broken into two projects.
  - Identification of replacement/new source:
    - Process map/C&E will focus on the process of identifying and screening potential candidates.
    - FMEA is a particularly good tool for this type of project to evaluate the candidates.
  - Implementation of the solution once identified
    - See instructions on Type 1 projects.
    - Example:
      - *A raw material change is needed, and the project needs to identify what the raw material substitution should be as well as implement the change. In the first project, map the process for identifying and screening materials. Use the FMEA to identify failures that could occur in this process. Once the project has selected the raw material(s) to substitute, start a second project to implement the change, while maintaining performance on the CTQ's.*

Project Charter Checklist

☐ What process is this project supposed to improve?
☐ In measurable terms, what is the project trying to accomplish?
☐ Is this project worth doing?
☐ Does it fit with the 3M objectives? Does it fit with the business strategic goals?
☐ Is this a customer-oriented project?
☐ Is the scope meaningful and manageable? Is it boiling the ocean or right size? Can it be completed in 6 months?
☐ What are the specific goals? Stretch targets?
☐ Who owns the process? Will they be involved?
☐ What is the probability of success?
☐ Can we get benchmark information? If so, where?
☐ What resources are available to the team?
☐ Who are the team members, process owner, and champion?
☐ What is the specific defect within the process? Is it clear and concise?
☐ Has this defect been worked on before and how are those efforts being leveraged or **replicated**?
☐ Has the potential financial benefit been identified and validated?
☐ How is Project Y currently measured?
☐ Is the baseline established?
☐ How was the entitlement determined?
☐ What percentage of the entitlement gap is being targeted by this project?
☐ What barriers to success exist?

Next Steps

After meeting with the project team to gain agreement on the project charter, begin the Process Map while also beginning to understand validity and reliability of data and gathering baseline data on your primary Y for initial capability.

Lessons Learned

B. Other Tools

- What's In It For Me (WIIFM) – Benefit Analysis (See appendix)
- Force Field Analysis (See appendix)
- Stakeholder Analysis and Influence Strategy (See appendix)
- RACI Matrix (See appendix)
- In-frame/Out-of-frame (See appendix)

Define Phase – Completion Checklist

☐ Completed initial project charter
☐ Specific and measurable project Y
☐ Project link to business winning strategies clearly understood
☐ Process boundaries documented and understood
☐ Process owner and champion defined
☐ Potential team members and stakeholders identified
☐ If you have a question – ASK!

III. Measure

Measure Phase Purpose:

- Define the current process
- Establish metrics
- Check quality of metrics

Measure Phase Goals:

- Document the process using a Process Map
- Identify process steps, outputs (Y's) and inputs (X's)
- Develop Cause and Effects Matrix (C&E) to help identify the critical inputs (X's)
- Establish Measurement System capabilities
- Establish baseline Process Capability for outputs (Y's)

Measure Phase Key Terms:

- **Y's – Outputs of Process (Noun)**
    - Process output variables or customer requirements
    - Associated with process performance/defect measures
    - Examples: % Lines-on-Time, % Deductions, % Sales by Store, Number rolls produced on line
- **X's – Inputs to Process (Noun)**
    - Process input variables
    - Associated with the sources of variation
    - Examples: Marketing programs, shelf placement of product, type of product, chemical mixture, manufacturing line

$$\boxed{y = f(x_1, x_2, \ldots, x_k)}$$

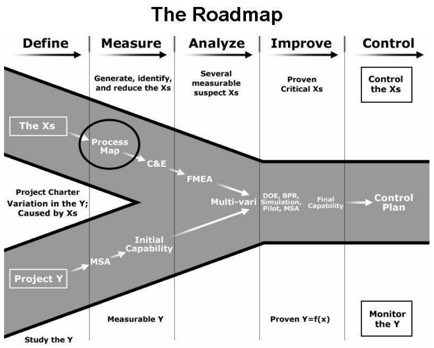
A. Process Map

Process Map Purpose:

- Identify the main steps, inputs, and outputs in the process being improved.
- Provide visual documentation and understanding of the current process.
- Provide input to other tools.
- Help clarify scope for the project.
- Ensures good team understanding of the process.

Process Map Goals:

- Clear understanding of process scope
- Agreement on key process steps and process inputs



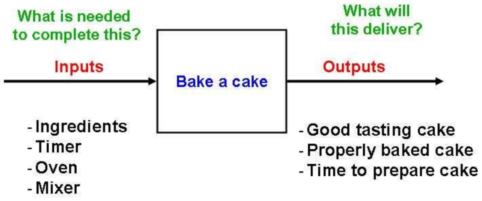
Steps to Create a Process Map

Useful items for process mapping: Brainstorming, existing documentation, experience of owners, operators, customers, suppliers and process observation.

Step 1 – Develop High Level Process Map (50,000 foot level)

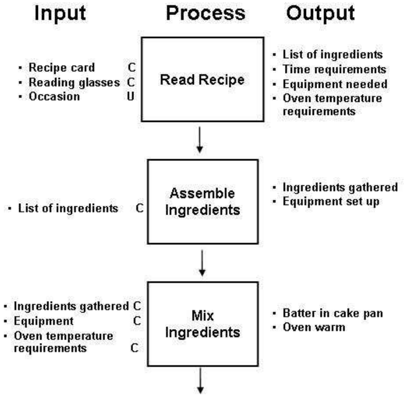
- **Identify process in simple terms** – typically from process definition on Project Charter
  - Crucial for success, but not always easy
  - If process not properly identified, subsequent efforts will be wasted
- **Identify major inputs** – typically include defects identified on Project Charter
- **Identify major outputs** – typically key metrics from Project Charter (Primary Y, Secondary Y, and Counterbalance Y)

Step 1: High Level Process Map
Cake Baking Example



Step 2 – Identify all steps in process (5,000 foot level) “What action happens?”

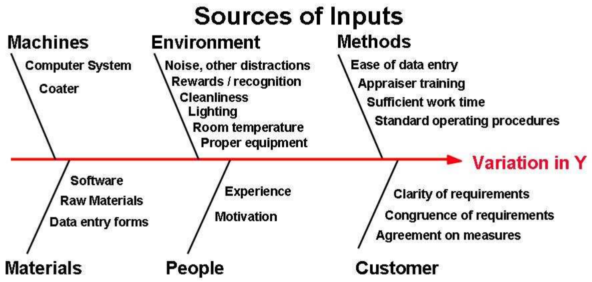
- Each step starts with a **verb** and describes activities that occur
- Most processes should be mapped in **6-8 steps** (if more than 8, scope may be too broad or you may be getting too detailed)
- Examples:
  - Transactional examples (business processes): Work activity steps, verification, rework, reprocessing
  - Operational examples (manufacturing processes): Process steps, inspection/test, rework, scrap points
- Include all value-added and non value-added steps
- **Hint**: Start with first step and last step, then fill in rest of the steps



Step 3 – List key outputs (Y’s) “What will the process step deliver?”

- Outputs should be **nouns** (not verbs) and describe what the process step will deliver
- Include tangible items and measures of performance (e.g. cycle time)
- Include both process and product output variables
- Output of final step should be Project Y
- Outputs should be measurable
- **Hint**: Focus on outputs that relate to Project Y

Step 4 – List and classify key inputs (X’s) “What is needed to complete this process step?”



- Inputs should be **nouns**
- Some inputs will be outputs from previous steps
- Make inputs quantifiable, if possible
- Don’t forget to include the people doing the work as inputs to the process BUT… Be specific: do not list “sales rep.” Instead list the specific attribute(s) of the sales rep that may be important (sales rep experience, sales rep availability, etc)
- **Classify** inputs as controlled (C) or uncontrolled (U) by someone in the process (today!)
  - **Controlled (C)** – Inputs that can be changed to see the effect on outputs
  - **Uncontrolled (U)** – Inputs that impact the outputs but are difficult or impossible to control (may also be controllable, just not under control currently)

Step 5 – Add process specifications for Inputs (X’s)

- For inputs identified as controlled and critical, add requirements and targets if they exist.
- Beginning of the control plan!

Elements of a Good Process Map

- Should describe:
  - Major activities/tasks
  - Sub-processes
  - Process boundaries
  - Input variables (X’s)
  - Output variables (Y’s)
- Should be reviewed frequently and updated
- Provides inputs to C&E matrix, FMEA, control plan, capability, and Multi-Vari studies
- Helps verify project scope
- Shows where the process starts and stops for your specific project.

Process Mapping Tips

- Good maps result from carefully observing the process
- Keep it simple, not complex (no massive wall charts, 6-8 steps only)
- Update process map as you move through the DMAIC roadmap
- If at all possible, get someone else’s process map to start
- To get full perspective, mapping must involve a **team**, not just one individual
- Process steps should be verbs (action); Inputs and outputs should be nouns (things)
- Use flip charts and Post-it notes (to move steps around while developing the map) or use the ubertool (Excel-based macro developed by 3M and available in the Six Sigma Information & Tools Database).
- Map the process AS IT IS TODAY, not how the team wishes it to be
  - **Hint**: If team identifies steps that are obviously missing, capture them on a different sheet and indicate where they should fit into the overall process map

Common Process Mapping Pitfalls

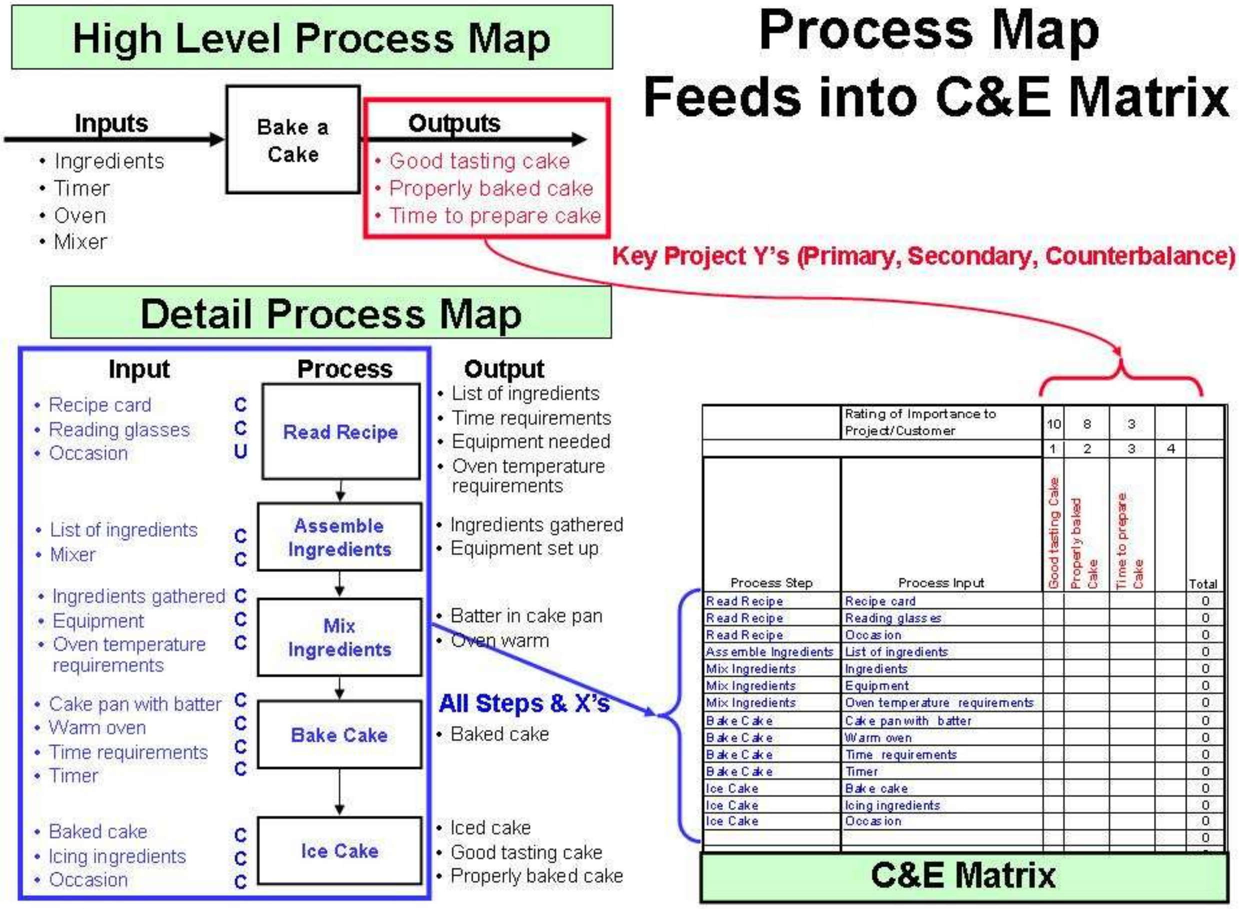
- Mapping the wrong process. Is this the process that’s causing the defects listed on the charter? If we improve this process will the defects be reduced?
- Inputs too generic – if the same input is listed at nearly all steps, be more specific
- Too many outputs – Focus on the most important outputs (related to the Project Y and the project metrics)
- Wrong outputs – Not focusing on outputs related to Project Y and project metrics
- Wrong level of detail - Too many steps or too few steps (lose sight of big picture)
- No operational definitions for inputs

Process Map Checklist

- ☐ Who helped developed the map and do they represent the key areas being mapped?
- ☐ Does the process map reflect the current state or the desired process?
- ☐ Are all non value-added steps included?
- ☐ What did you learn from the process map?
- ☐ What quick hits did you find from this effort?
- ☐ What process steps do the team feel can be eliminated or combined to reduce opportunities for scrap and increase rate?
- ☐ How will you measure the inputs (X’s) and outputs (Y’s)?
- ☐ Are the inputs (X’s) identified as controlled/uncontrolled?

Next Steps

Take all process steps and inputs (X’s) into the Cause & Effect (C&E) Matrix. Take only the major outputs (Y’s from the high-level process map) into the (C&E) Matrix. These must include the Project Y’s and counter balance Y.



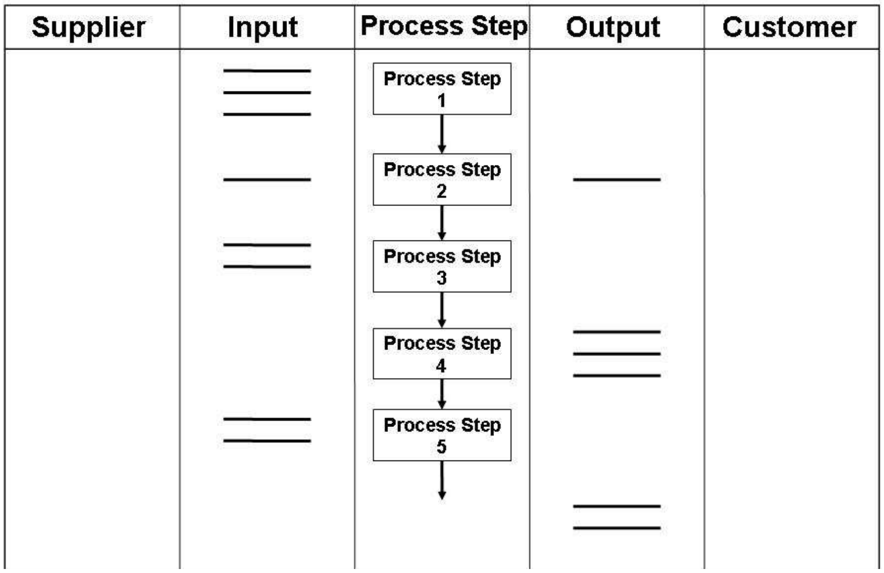
	Rating of Importance to Project/Customer	10	8	3		
		1	2	3	4	
Process Step	Process Input	Good tasting Cake	Properly baked Cake	Time to prepare Cake		Total
Read Recipe	Recipe card					0
Read Recipe	Reading glasses					0
Read Recipe	Occasion					0
Assemble Ingredients	List of ingredients					0
Mix Ingredients	Ingredients					0
Mix Ingredients	Equipment					0
Mix Ingredients	Oven temperature requirements					0
Bake Cake	Cake pan with batter					0
Bake Cake	Warm oven					0
Bake Cake	Time requirements					0
Bake Cake	Timer					0
Ice Cake	Bake cake					0
Ice Cake	Icing ingredients					0
Ice Cake	Occasion					0
						0

Lessons Learned

SIPOC (Suppliers-Inputs-Process-Outputs-Customers)

An extension of the regular process map is called the SIPOC map. The SIPOC is the same as the regular process map with the addition of displaying who supplies Inputs (Suppliers) and who receives Outputs (Customers). The SIPOC shows how no organizational process "stands alone." Rather, all processes are in some way connected to other processes in the organization.

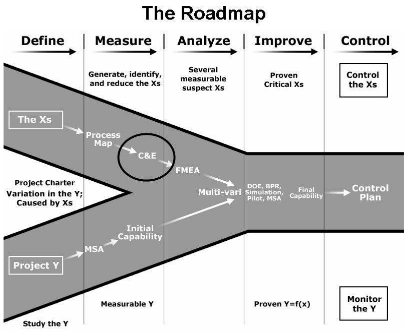
- A SIPOC shows the "touch points" of the process under study to other processes (or departments). Knowing these "touch points" enables a more thorough understanding of the issues when considering process improvement work
- Two key uses of SIPOCs:
    - During the Define phase
        - High-level (50,000 ft view) only
        - To better understand the scope of a potential project and to better identify stakeholders in the project
    - During the Measure phase
        - Same level of detail as basic process map
        - To better understand who are the customers and suppliers and to better understand their requirements



Other Process Understanding Tools (see Black Belt or Coach for details)

- Cross Functional Process Map (Swim Lane Diagram)
- Value Stream Mapping (Value-Add/Non-Value-Add Flow Charts)
- Affinity Diagrams
- Interrelationship Digraphs
- Fishbone Diagrams
- K-J Analysis

B. Cause and Effects (C&E) Matrix



Cause & Effects (C&E) Matrix Purpose:

- Prioritize the inputs (X's) identified from the detailed process map based on their impact on the high-level project outputs (Y's).
- The C&E Matrix is a simplified QFD (Quality Function Deployment) matrix to emphasize the importance of understanding customer requirements.
- Provides comprehensive evaluation of all Inputs (X's) at once – prioritize most important variables across entire process.

Cause & Effects (C&E) Goals:

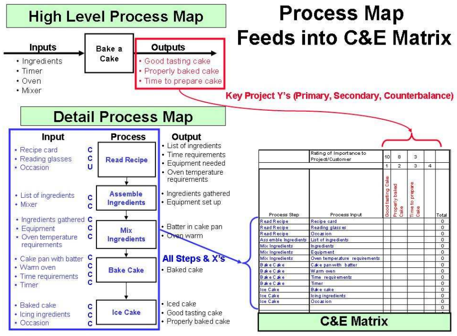
- Inputs (X's) prioritized

Steps to Create a C&E Matrix (General Method)

- Two methods to build a C&E Matrix:
  - General Method (discussed below)
    - Preferred when number of input variables is manageable **(e.g. less than 150)**
    - Examine **all input** variables at once
  - Focused Method (see "C&E Matrix Hints" section for instructions)
    - Preferred when **number** of input variables becomes **too large** to manage effectively
    - Focus on **process steps**, then drill down on variables in the highest priority steps first

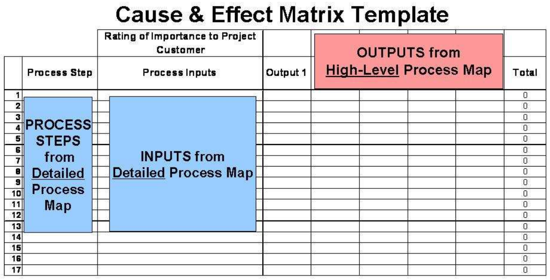
Step 1 – List Key Project Outputs (Y's) from High Level Process Map

- Select the key outputs – typically the Primary Y, Secondary Y, and Counterbalance Y. Ideally, 3-5 outputs – no more than 10! These outputs should be measurable. (**Hint:** Typically these outputs are the final outputs of the process.)
- Place Outputs across the **top** of the C&E Matrix.
- Develop written **operational definitions** for each of the Outputs listed to ensure equal understanding. These definitions should be entered as comments (see below) on the Excel cell, or listed on a separate worksheet for continual access while working on the C&E.



Step 2 – Rate Outputs to project importance

- Weight from 1-10, where 10 is "extremely important." Primary Y should generally be 10, Secondary Y often 6-8, Counterbalancing Y often 3-5. Everything else less than Primary Y.
- Be ruthless in prioritization – not every Output (Y) can be a "10" in importance.
- Look for balance between Y's
  - If several similar Y's are listed, when taken together they may outweigh a single more important Y
  - Example: Y's of "cost" and "price". Price is defined as what is paid in $, Cost is defined as price paid <u>AND</u> performance received from product. If both price and cost are included on C&E, price gets double weighted.



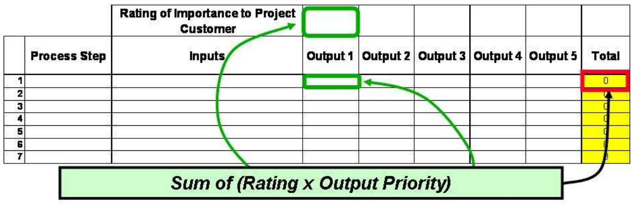
Step 3 – Transfer <u>all Inputs</u> (X's) from the Detailed Process Map

- Remember to include the corresponding Process Steps with the Inputs (X's).
- Include any Input (X) operational definitions.

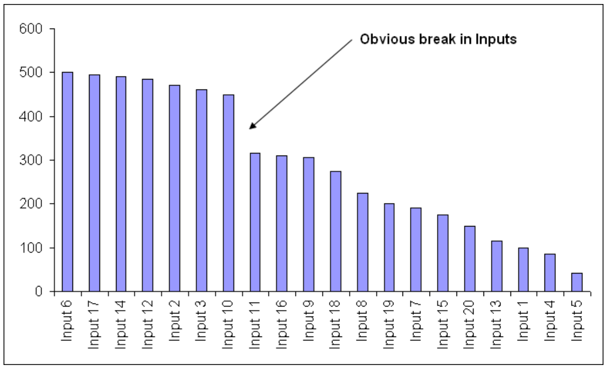
Step 4 – Evaluate each Input (X) for its effect on each Output (Y) by reaching a team consensus

- Use the following phrase as you read each <u>Process Step</u>/<u>Input</u> line of the C&E Matrix: *In the Process Step of ___________________, what effect or impact does process <u>Input</u> (X) ____________ have on (the first <u>Output</u>/Y on top of the C&E) ____________? What impact does it have on the second Output? The third? Etc.*
- Use the following guide for rating each "process input." Use <u>**only**</u> 0, 1, 3, 9. Agree to project specific (or Output specific) operational definitions before begin scoring. Do <u>**not**</u> ask if the X's and Y's correlate. Rather ask how <u>strong the effect</u> of the X is on the Y (output being discussed).
  - 9 - If input has a **direct & strong** effect on output
  - 3 - If input has a **moderate** effect on output
  - 1 - If input has a **remote/slight** effect on output
  - 0 - If input has **no effect** on output
- Team makeup is critical. Need representation from all functions.
- <u>Inserting comments in Excel:</u> If team is disagreeing on the rating, enter the highest effect of the disagreed values in the cell. If working in Excel, do a right-mouse click over the cell and choose "Insert Comment". Type in the reasons for the two different values (e.g. "felt to be a 9 because…. felt to be a 3 because…"). Then, when the data is sorted, the items with discussion on them will have a red corner in their cell.

Step 5 – After scoring all Inputs to Outputs, Excel calculates a total score for each input (Input score multiplied by the Output weighting factor; summed for each Input).



Step 6 – Sort the Input rows in descending order by total score (always save the data first) and do "gut check".



- If desired, create a Pareto chart of the descending scores to find the natural break. To create a Pareto chart in Excel:
  1. Ensure the data is sorted in descending order by "total score".
  2. Highlight the entire area of the C&E containing the inputs, rated values, total score and column headings.
  3. Choose *Insert > Chart > <u>Chart Type</u> is "Column" and click "Next".*
  4. *Click on "Series" tab.*
     a. *In the <u>Series</u> box, click on each of the series descriptions and choose "Remove" until only the "Total Score" is left in the box.*
     b. *In the <u>Name</u> box, the cell containing the column name for the "Total Score" should be selected.*
     c. *In the <u>Values</u> box, the range containing the "Total Score" should be selected.*
     d. *In the <u>Category X Axis Labels</u> box, the range containing the "Inputs" should be selected and click "Next".*
  5. *Click on "Legend" tab and click off the "Show Legend" box and click "Next".*
  6. *Click on <u>As New Sheet</u>, enter title for worksheet and click "Finish".*
- Do a "gut check" to see if most important Inputs (X's) have risen to the top. Ask your team: Should the top X's be top X's? Are some X's missing? Why or why not?
- If the most important Inputs (X's) have <u>not</u> risen to the top, as a team review the scoring and discuss.
- Based on the scores/Pareto chart, along with team "gut check", determine which inputs to take forward into the Failure Modes & Effects Analysis (FMEA). Ideally, take no more than 3-7 inputs into the FMEA.

C&E Matrix Hints

- If the team can't agree on a rating, check that everyone is using the same definition of the input; definition may need to be made more specific. When in doubt, use the higher rating. Remember that 0's and 1's won't rise to the top anyway, so long debate here isn't useful.
- If a team member is being too vocally dominant during the scoring, hand out flash cards to each person (0,1,3,9) so they can each hold up their score and be represented. Discuss differences in values.
- Use the C&E Excel template to automatically calculate the total score for each Inputs (X).
- Entire team should work together to build C&E Matrix. Team makeup is critical. Obtain good representation from many functions – including subject matter experts (SME's).
- Stay close to three measurable Outputs (Y's) across top.
- Every Input (X) from the Process Map is brought to the C&E.
- Hide the "total" column – this keeps people from ranking so that their "pet" input is rated high.
- Rank and score representing what could happen, not necessarily what has happened or what is happening.
- When there are more than 150 Inputs (X's), follow the "Focused" method:
  - **Phase 1**
    - Place **Project Outputs** (Y's) across top of matrix and assign importance scores, as usual
    - Place **process steps** (only steps, not Inputs) down side of matrix
    - **Assign scores** for correlation between process steps and output variables
    - **Calculate weighted** importance scores and rank process steps from high to low
  - **Phase 2**
    - Start a new *(General Method)* C&E matrix with inputs from top three or four process steps identified in Phase 1
- Cause & Effects Matrix feeds into 3 tools:
  - Key Inputs are fed into **FMEA**
  - Provides input to **capability study**
  - Provides input into initial evaluation of **control plan**

Common C&E Matrix Pitfalls

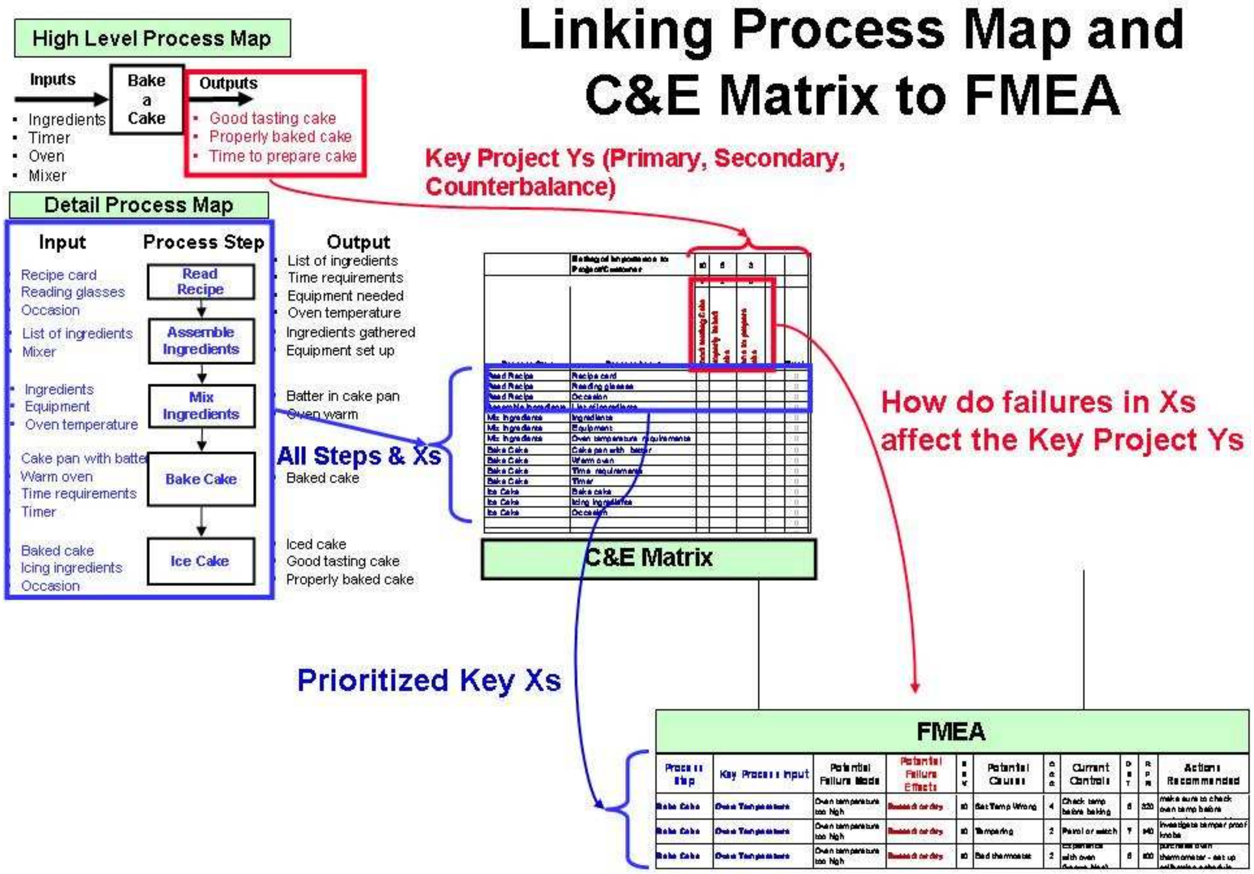
- Voting & averaging scores: team discussion and consensus is vital to understanding the process
- No operational definitions for ratings: need agreement!
- No team discussion and consensus on rating scales: need everyone's input!
- Too many Y's: use only the most important Y's from the charter and the high level process map
- Adding a 6 to the scoring or scoring 1-10: only use 0,1,3,9 to create differentiation between the Inputs (X's)
- Scores for Y's aren't differentiated enough (10,10,9)

C&E Matrix Checklist

☐ Who provided inputs to the customer requirements for this C&E Matrix?
☐ Who determined the relationship ratings for the Inputs (X's) and Outputs (Y's)?
☐ What surfaced as the top Inputs (X's) from the C&E Matrix? Do these make sense?
☐ What actions are being taken on the top ranked Inputs (X's)?
☐ Are there any "quick hits" that can be assigned to lower ranking Inputs (X's)?
☐ Do the current control plans reflect the need to monitor these top Inputs (X's)?

Next Steps

Take the top items from the C&E matrix into the Failure Modes and Effects Analysis (FMEA).

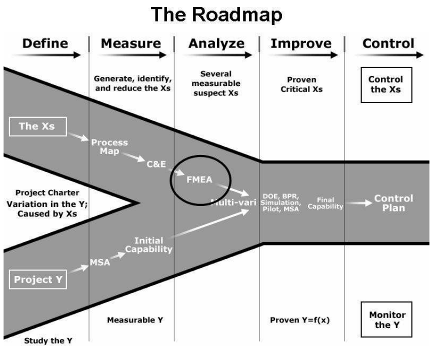


Lessons Learned

C. Failure Modes & Effects Analysis (FMEA)

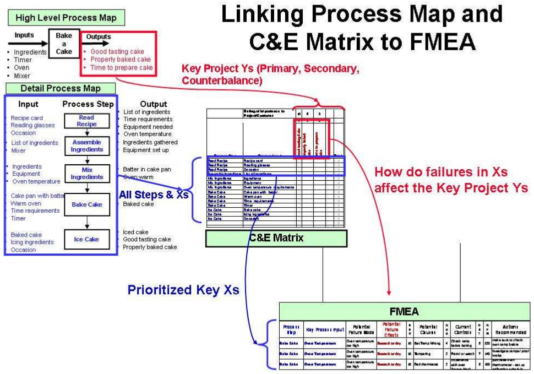
Failure Modes & Effects Analysis (FMEA) Purpose:

- Identify ways the inputs (X's) can fail and determine the effect of the failures on the outputs (Y's).
- FMEA is a structured approach to estimate risk associated with specific failures and to prioritize actions that should be taken to reduce the risk. The FMEA also identifies current controls.
- Used to prioritize risk to ensure process improvement efforts are beneficial and timely (internal and external)
- Used to document completion of projects (actions completed)
- Should be a dynamic document, continually reviewed, amended, and updated (one of the control documents)



Failure Modes & Effects (FMEA) Goals:

- Key inputs (X's) narrowed down to be taken into Analyze phase and potentially controlled
- Failure causes of key inputs (X's) identified
- Prioritized list of actions to prevent Causes or detect Failure Modes
- Record of Controls and actions taken
- Deeper process understanding for the team



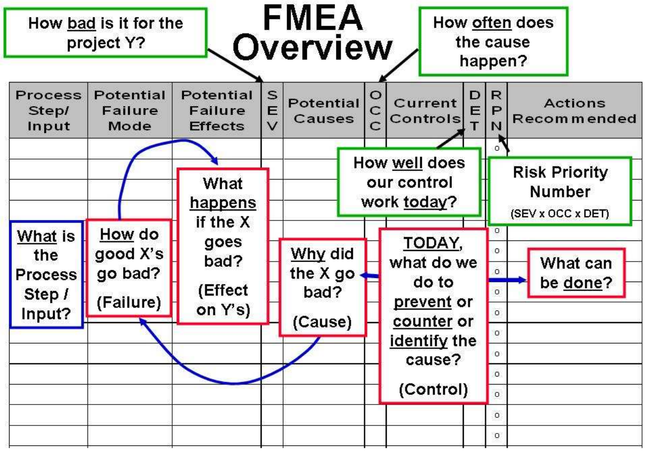
Steps to Create an FMEA

Setup:

- Identify a good cross-functional team. Include subject matter experts (SME's), facilitator, functional process participants/operators, etc.
- Bring prioritized inputs (and their process steps) from the C&E into the FMEA. Ideally, take no more than 3-7 inputs into the FMEA.

Step 1 – Identify Failure Modes

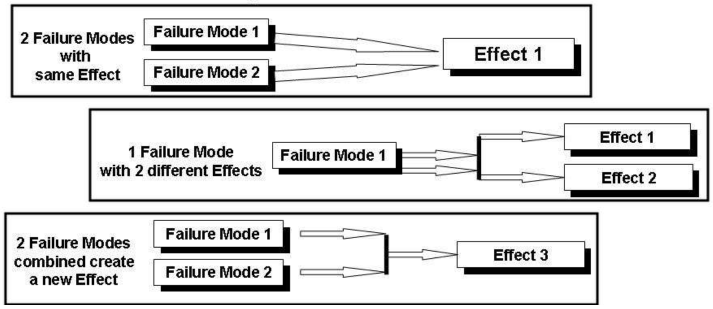
- Starting with the first input, list all Failure Modes on individual lines.
- Failure Modes identify ways a specific input fails (can fail in multiple ways). The failure could be due to a defect or because the input goes out of the customer specifications. If the failure is not detected and either corrected or removed, it will cause the effect to occur.
- **Failure Modes** answer: *"How do good X's go bad?"*
- **Hint:** Failure modes should be easy to identify. If you have more than 5, you may be including causes.



Step 2 – Determine Effects

- For the input (X), list all possible failure Effects within this process step. Effects are caused by an X failing (Failure Mode). If the input fails, any or all of the Effects could occur.
- Effects identify the impacts of the failure on the customer requirements or project outputs (Y's). Remember to include what might happen. **Be descriptive** about what happens to the process (e.g. production stops).
- **Effects** answer *"What happens to the process customer when the X goes bad?"*
- **Hint:** List all the Effects for each Failure Mode in one cell to assist with later scoring (see Step 5).
- **Hint**: Relationship between Failure Mode and Effect is <u>not</u> always 1-to-1 (see diagram "Linking Failure Modes to Effects").
- **Hint:** Effects should be one step below project Y.

Linking Failure Modes to Effects



Step 3: Identify Causes

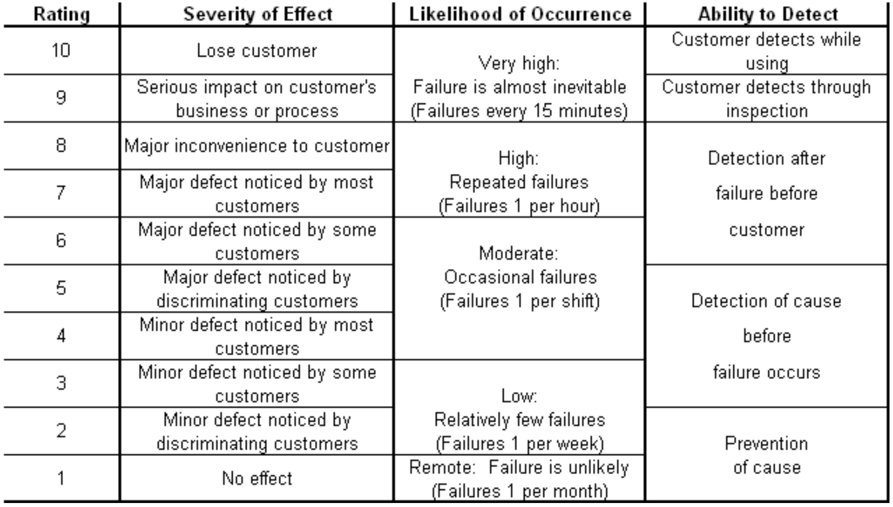
- For each Failure Mode, list the <u>immediate</u> Cause of the failure.
- Often there are several Causes for each Failure Mode.
- **Causes** answer: *"<u>Why</u> did the X go bad?"*
- **Hint:** Causes cause Failure Modes, NOT Effects. <u>Do not</u> need the same number of Causes as Effects. May find it helpful to <u>hide</u> the <u>Effects</u> column.
- **Hint:** Remember the scope of your project – the Window of Consideration. Can use a little Process Map for each Failure Mode: Causes are Inputs, Failure Mode is Process Step, Effects are Outputs.

Step 4: List Current Controls for Causes

- For each Cause, list Controls that are currently in place to prevent the Cause or Failure Mode, or detect the Failure Mode (currently in place – not what ideally should be in place).
- Controls consist of audits, checklists, inspection, laboratory testing, training, SOPs, preventive maintenance, databases, etc. Sometimes there are no Controls for a Cause or Failure Mode.
- Helps identify gaps in our current controls. Sometimes there are no controls for a Cause or Failure Mode.
- **Controls** answer: *"<u>TODAY</u>, what do we have in place to prevent, counter or identify the Cause before the customer sees the Failure associated with it?"*
- **Hint:** Controls can be listed in one cell as a system of things that work together.

Step 5: Determine Rating Scales (Never use a 0)

- For your project, customize definitions for the scales of Severity (SEV), Occurrence (OCC), and Detection (DET). See chart.
- **Severity (of Effect)** – **Importance** of Effect on customer or process requirements – should relate to project Y's. Also consider safety and other potential risks. (1= None to Very Minor; 10=Very Severe)
- **Occurrence (of Cause)** – **Frequency** the Cause occurs and creates the Failure Mode. May refer to the frequency of a Failure Mode. (1=Not Likely to Occur; 10=Very Likely to Occur)
- **Detection (capability of current Controls)** – **Ability** of current control scheme to detect or prevent: the Causes before creating Failure Mode **or** the Failure Modes before causing Effect. (1=Likely to Detect or Prevent; 10=Not Likely to Detect)
- Other categories can be added:
  - For example, one engineer added an impact score to RPN calculation to estimate overall impact of Failure Mode on process.
  - Another example is using two Severity columns: severity to external customer; and severity to internal customers and processes.
- Typical rating scale is 1-10. Allows for better precision in estimates and a wide variation in scores. Remember: Never include a 0 (zero)!



Rating	Severity of Effect	Likelihood of Occurrence	Ability to Detect
10	Lose customer	Very high: Failure is almost inevitable (Failures every 15 minutes)	Customer detects while using
9	Serious impact on customer's business or process		Customer detects through inspection
8	Major inconvenience to customer	High: Repeated failures (Failures 1 per hour)	Detection after failure before customer
7	Major defect noticed by most customers		
6	Major defect noticed by some customers	Moderate: Occasional failures (Failures 1 per shift)	
5	Major defect noticed by discriminating customers		Detection of cause before failure occurs
4	Minor defect noticed by most customers		
3	Minor defect noticed by some customers	Low: Relatively few failures (Failures 1 per week)	
2	Minor defect noticed by discriminating customers		Prevention of cause
1	No effect	Remote: Failure is unlikely (Failures 1 per month)	

Step 6: Assign SEV, OCC, and DET Ratings

- Assign ratings to the SEV, OCC, and DET columns for every value by asking the following questions:
  - **Severity**: *"In ___________ (Process Step), when ____________ (X) fails by ___________ (Failure Mode), how bad is it if the customer sees ___________ (Effect)?"* **Note:** For the combined Effects, determine which Effect in the combined cell is most severe. The score for this Effect is used for **all** the Effects listed for that Failure Mode.
  - **Occurrence:** *How often does __________ (Cause) occur?*
  - **Detection**: ***Today****, how good is our Control of ______________ at catching or preventing the Cause of _______________ before it affects the customer?* **Note:** Possible that current control method cannot detect cause but does detect failure mode. Example: 1 = prevention, 10 = detect too late/no detection. (Note reverse scale!!)

Step 7: Calculate RPN's

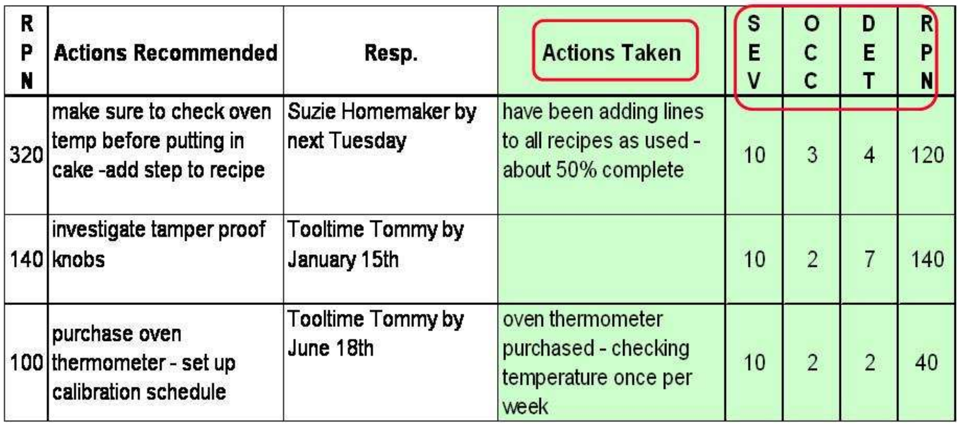
- After all scoring is complete, fill any empty cells with the appropriate Failure Mode and combined Effect. Each Cause must have an associated Process Step, Input, Failure Mode and Effect cell.
- Save the worksheet and sort the entire worksheet by the RPN (risk priority number) column in descending order.
- If desired, create a Pareto Chart to see where the natural break in the scores occurs.
- Review the results and look for insights.
- **Hint:** Do a "gut check" to see if the most important X's have risen to the top. Ask your team: "*If we improve these top X's, will we accomplish our project Y?*" If not, maybe the ratings given need to be reviewed.
- **Hint**: Make a backup copy of the file before sorting.
- **Hint:** Team will often take the Failure Modes and Causes for the top X's to write hypothesis statements for Multi-Vari work. During the Multi-Vari step data is collected to prove/disprove these hypotheses.

Step 8: Create Action Items for "High" RPNs and Assign Responsibilities

- Only identify actions for high RPN's.
- Also look at all Causes with a Severity rating of 10. Should these also have a Recommended Action?
- Be sure to identify who will do the actions and the time the actions are due. Assign specific people (not functions or positions).

Step 9: Take Actions & Recalculate

- Indicate actions taken by team members and the results.
- Recalculate RPN ratings as actions are taken. Sort for new prioritized RPN's and assign additional action items if necessary.

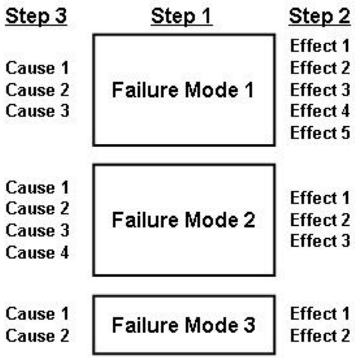


RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
320	make sure to check oven temp before putting in cake -add step to recipe	Suzie Homemaker by next Tuesday	have been adding lines to all recipes as used - about 50% complete	10	3	4	120
140	investigate tamper proof knobs	Tooltime Tommy by January 15th		10	2	7	140
100	purchase oven thermometer - set up calibration schedule	Tooltime Tommy by June 18th	oven thermometer purchased - checking temperature once per week	10	2	2	40

FMEA Tips

- Complete the FMEA columns for all of the textual columns (Failure Mode, Effect, Cause, Control) for each input first. Then, complete the numerical columns (Severity, Occurrence, Detection). Don't complete the "Actions recommended" column until all scoring is complete. Occasionally capture any solution ideas that arise here, but refrain from letting the team brainstorm solutions at this time.
- Hide ***Effects*** column when listing ***Causes*** of ***Failure Modes***. This can address the pitfall of linking ***Causes*** to ***Effects***, instead of to ***Failure Modes***.
- Do not schedule more than 2-3 hour blocks of time for working on the FMEA or the team will lose interest.
- Be sure the "detection" scores are in right order (reverse score of other scales). Example: 1 = prevention, 10 = detect too late.
- Remember – no 0's in numerical scales!
- A cross-functional team approach is required for completion of a successful FMEA. Use subject matter experts to supplement team knowledge as needed. Team should have the minimum number of appropriate people necessary to understand how the X's fail and what impact that has on the Y's. Too many members increases confusion and slows the process. Consider using a facilitator or your BB.
- If there is a dominant team member, written scorecards can help begin the scoring discussion so the same person doesn't always decide the score. Another approach is to go around the room one at a time, and start with a different person each time.
- Frequently save your spreadsheet!
- Some teams find it helpful to think of following the "Process Map" model to complete the FMEA. This approach can be used to complete only the Failure mode, Effect, and Cause columns of the FMEA. The form and layout is similar to a Process Map. (Check out the "FMEA Generator" Excel file in the Information and Tools database to help use the "process map" model.)

  Step 1 – List Failure Modes as if they were process steps.
  Step 2 – List Effects as if they were outputs.
  Step 3 – List Causes of the Failure Modes as if they were inputs. (Might hide the Effects column when doing this step.)



  - Completing the information this way helps eliminate confusion caused by the layout of the standard FMEA form. It also helps separate Causes from Effects. Doing this in Excel can be very helpful because when you are done, you can copy and paste the columns into the FMEA worksheet.
  - In the regular FMEA worksheet, continue with the FMEA form. Rank the Severity of Effects and combine them before the Causes are listed. After this, the process is the same as the standard method.

Common FMEA Pitfalls

- Rushing through FMEA instead of taking time to do it well (May result in Multi-Vari study being skewed).
- Using voting and averaging instead of discussion and consensus.
- No team discussion and consensus on rating scales and/or operational definitions for ratings.
- Taking too many X's into the FMEA - ideally only take 3-7 inputs from C&E into FMEA.
- Choosing the wrong window of consideration. Effects need to be tied to Project Y. Failure Modes need to have an impact on Effects.
- Not digging into the real issue – being too superficial
- Wrong people on the team: need good mix of people who understand the process thoroughly.
- Forgetting Project Y or forgetting who the customer is – lose focus on purpose of project.
- Causes listed in the Failure Mode column. If have more than 5 Failure Modes for one X, you probably are incorrectly listing causes.

FMEA Checklist

☐ Who helped developed the FMEA – did we involve the necessary organizations?
☐ Which items from your C&E Matrix did you evaluate in the FMEA?
☐ Does the FMEA reflect the current state?
☐ Did you customize the ranking system for your project?
☐ What quick hits did you find from the FMEA?
☐ Did you complete the "actions recommended" section of the FMEA?
☐ Do all actions in your FMEA have responsibilities assigned and a completion date identified?
☐ Have you updated your Control Plan with what you know so far?
☐ Can you obtain data for top scoring X's? Causes? Failure Modes?

Next Steps

Determine further data collection, conduct Multi-Vari studies, experiments or develop process improvements. Take action on any "quick hit" improvements with low or acceptable risks.

Lessons Learned

D. Types of Data

Data can be grouped into several categories including:

Discrete – (Attribute or Qualitative)

- Refers to descriptive characteristics
- Expressed in “verbal” terms and descriptions
- Can be quantified by counting frequency of occurrences
- Examples:
    - Color of eyes: blue, green, brown, etc.
    - Socio-economic status: high, middle, low
    - Categories: good / bad, machine 1 / machine 2
    - Steak: Rare, medium rare, medium, well done

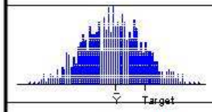
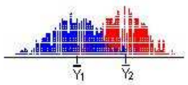
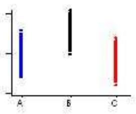
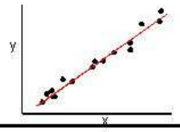
Continuous – (Variables or Quantitative)

- Characteristics expressed in numerical form
- If you can divide by two and it makes sense it is continuous
- Examples:
    - Time: 2.000, 2.1, 2.119 seconds
    - Pressure: 45, 45.8, 49.234 psi
    - Cycle time: 8, 14, 32 days

Count

- Number of errors in document, # units shipped, etc.
- Treat as discrete if occurrences are rare (e.g., errors in simple documents) or the range is less than 10 (e.g., all counts are between 105 and 112)
- Treat as continuous if occurrences are frequent (e.g., units shipped)

Why is the type of data important? Based on the type of data, the appropriate analysis tool can be determined.

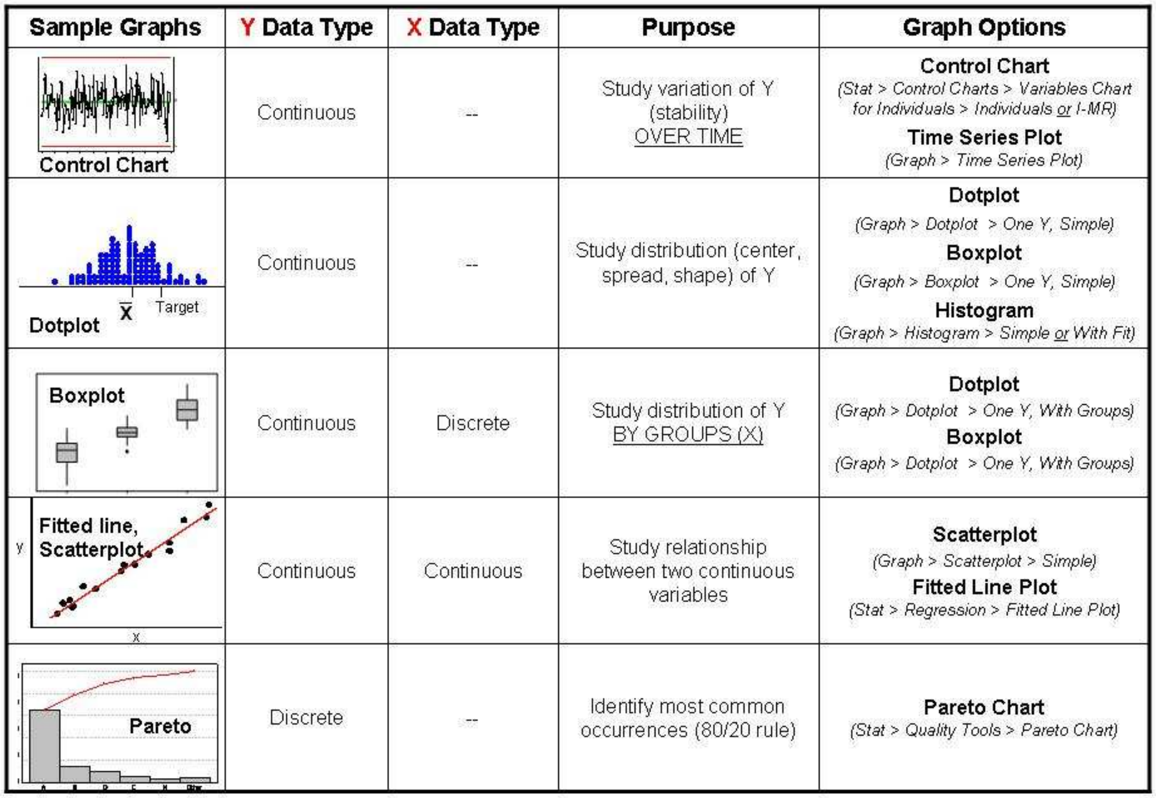
Data	Description	Hypothesis	Graphical Tool	Test
A B C R 5 10 25 S 80 50 75	Discrete X Discrete Y	H_0: Factors are independent	Not Applicable	Chi-Square
	Continuous Y compared to target/goal	$H_0: \mu = \text{Target}$	Box plot, Dot Plot	1-Sample t
	2 levels of Discrete X, Continuous Y	$H_0: \mu_1 = \mu_2$	Box plot, Dot plot, Main Effects	2-Sample t
	3+ levels of Discrete X, Continuous Y	$H_0: \mu_1 = \ldots = \mu_k$	Box plot, Dot plot, Main Effects	ANOVA
	Continuous X; Continuous Y	H_0: Slope = 0	Scatter plot, Matrix plot	Regression

E. Graphs

Many graphs are available to visually understand the nature of variation. For many people "a picture is worth a thousand words."

- Graphs should be the primary presentation tool for data analysis. If you can't show the analysis graphically, you probably don't have a good conclusion.
- Graphs can help separate signal from noise.
- Behavior can be described by plotting data points for the input (X) or output (Y): over time, across products, on different machines, etc.
- Some of the graphs that can be used to represent the data include the following. See the Information & Tools database for "Graphs for DMAIC" for help with creating and interpreting the graphs.
  - Dotplots
  - Histograms
  - Box Plots
  - Scatter Plots
  - X-Y Plot
  - Concentration Diagrams
  - Fitted Line Plot
  - Normal Probability Plot
  - Pareto Diagram
  - Matrix Plot
  - Contour Plot
  - Pie Chart
  - Bar Chart

The grid below shows the graphs commonly used on Green Belt Projects and how to create them in Minitab. **Hint:** When running the test in Minitab, almost always put the output (Y) in the first box and the input (X) in the second box.



Sample Graphs	Y Data Type	X Data Type	Purpose	Graph Options
Control Chart	Continuous	--	Study variation of Y (stability) OVER TIME	**Control Chart** *(Stat > Control Charts > Variables Chart for Individuals > Individuals or I-MR)* **Time Series Plot** *(Graph > Time Series Plot)*
Dotplot X̄ Target	Continuous	--	Study distribution (center, spread, shape) of Y	**Dotplot** *(Graph > Dotplot > One Y, Simple)* **Boxplot** *(Graph > Boxplot > One Y, Simple)* **Histogram** *(Graph > Histogram > Simple or With Fit)*
Boxplot	Continuous	Discrete	Study distribution of Y BY GROUPS (X)	**Dotplot** *(Graph > Dotplot > One Y, With Groups)* **Boxplot** *(Graph > Dotplot > One Y, With Groups)*
Fitted line, Scatterplot y x	Continuous	Continuous	Study relationship between two continuous variables	**Scatterplot** *(Graph > Scatterplot > Simple)* **Fitted Line Plot** *(Stat > Regression > Fitted Line Plot)*
Pareto	Discrete	--	Identify most common occurrences (80/20 rule)	**Pareto Chart** *(Stat > Quality Tools > Pareto Chart)*

Data analysis tasks for improvement

1. **Stable** – Is process stable over time? If process is not stable, identify and remove causes of instability (if they make the process worse).
2. **Center** – Is the mean on target? If not, identify the variables that affect the mean and determine optimal settings to achieve target value.
3. **Spread** – Is the variability acceptable with respect to the customer requirements or project goal? If not, identify the sources of the variability and eliminate or reduce their influence on the process.
4. **Shape** – Does the data look like a bell shaped curve? Are there outliers? Talk to your Black Belt or Coach with problems!

F. Basic Statistics

We generally want information about a population. However it is often difficult to measure the entire population. Even if we can measure the entire population today, we usually want to predict what will happen in the future. We get information about populations by collecting a sample of data. Statistics are characteristics of the **sample**, and they're used to estimate characteristics of the **population.**

Measures of Central Tendencies

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

- **Mean:** Average of a set of values
  - Reflects the influence of all values
  - Strongly influenced by extreme values
- **Median:** Reflects the 50% rank - the center number after a set of numbers has been rank ordered
  - Does not necessarily include all values in calculation and is "robust" to extreme scores
- ***In Minitab:*** To obtain the measures of central tendencies for a process in Minitab:
  Stat > Basic Statistics >Graphical Summary > Variable: Select Y

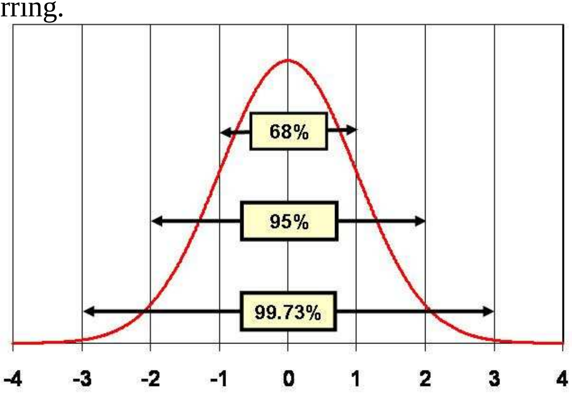
Measures of Variability

$$\hat{\sigma} = s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

- **Range:** Distance between the extreme values of a data set (Highest - Lowest)
- **Variance (σ^2, s^2):** Average squared deviation of each data point from the mean
- **Standard Deviation (σ, s):** Square root of the variance. Equivalent to the average distance from the mean.
- ***In Minitab:*** To obtain the measures of variability for a process in Minitab:
  Stat > Basic Statistics >Graphical Summary > Variable: Select Y

Normal Distribution

- **Property 1:** A normal distribution can be described completely by knowing only the Mean and Standard Deviation.
- **Property 2:** The area under sections of the curve can be used to estimate the cumulative probability of a certain "event" occurring.

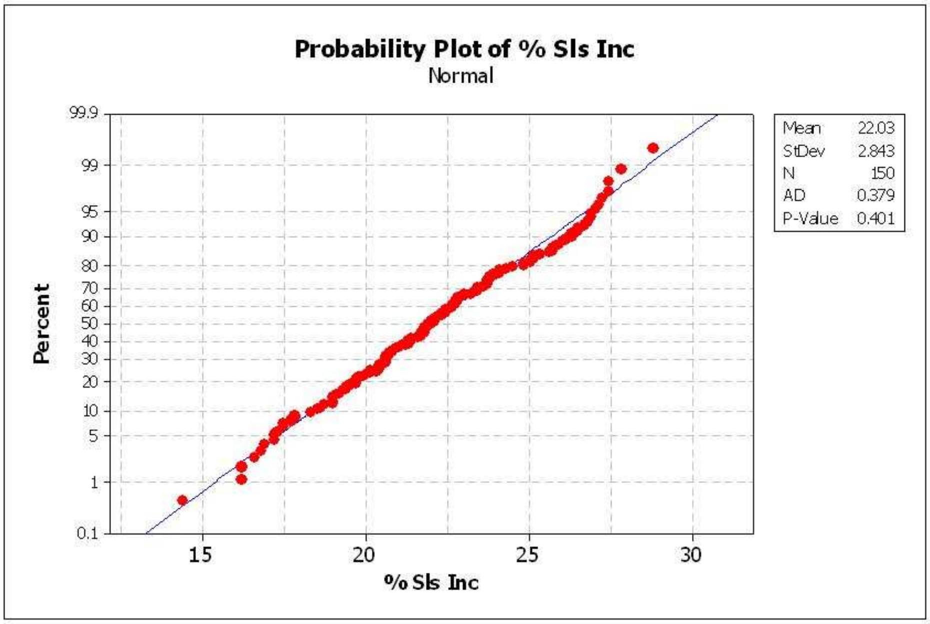


- **Property 3:** Previous rules of probability apply even when a set of data is not perfectly normally distributed. Comparison of values for theoretical (perfect) normal distributions to empirical (real-world) distributions:

  If the data are normally distributed, then many of the statistical tools can be used. If the data are not normally distributed, then caution must be used with some of the statistical tools. Contact your Black Belt or coach.

Number of Standard Deviations	Theoretical Normal	Empirical – Almost any distribution
+/- 1σ	68%	60-75%
+/- 2σ	95%	90-98%
+/- 3σ	99.7%	99-100%

- ***In Minitab:*** To see if a process is normally distributed in Minitab:
  Graph > Probability Plot > Single > Variable: Select Y
  Results: If the data points are close to the line or could be covered with a "fat pencil", the data are normally distributed.



Preliminary Data Analysis

- All the methods can provide insight on how to graphically represent data.
- Data analysis should follow some basic steps:
    - Practical – Always check raw data to identify any abnormalities (errors, unexpected values).
    - Graphical – Analyze data graphically to get a sense of overall shape and time trends.
    - Analytical – Use other analysis methods to analyze why data is a certain way (e.g. t-Test, ANOVA, Regression).

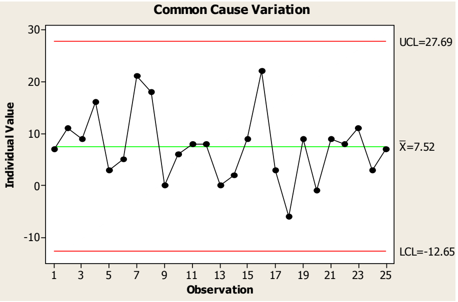
G. Statistical Process Control (SPC)

Statistical Process Control (SPC) Purpose:

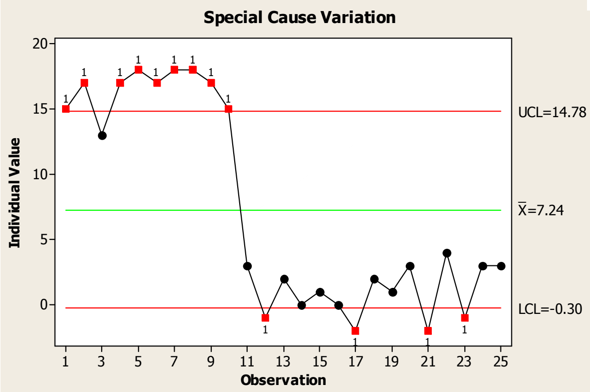
- Determine the ability of the process to perform in a predictable manner over time. This is also called the stability of a process.

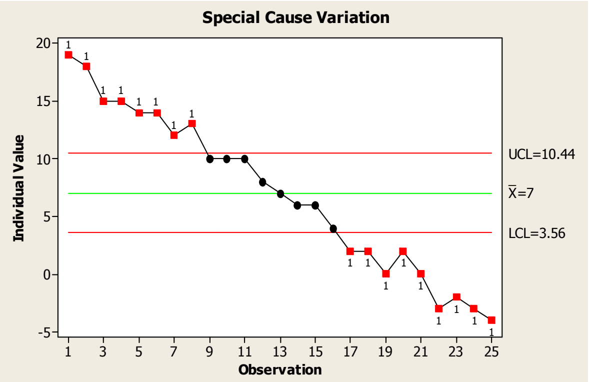
Common Cause & Special Cause Variation

Variation exists in every process. Once the type of variation is understood, the improvement method can be determined.



- **Common Cause** variation (noise) is controlled variation. This is the "random variation" present in every process.
    - A process is ***stable***, ***predictable***, and ***in-control*** when only common cause variation exists in the process.
    - The cause of the variation may be known or unknown. The amount of variation may be large or small.
    - Common cause variation is produced by the process itself (the way we do business).
    - If common cause dominates, make a permanent change to the entire process. Do not tamper with point to point variation. Instead drill down to isolate sources of the problem (e.g., by department, product, customer, etc.), study the sub-processes to isolate constraints, or experiment and evaluate the results. Ask "What is *happening* (throughout the whole time span)?"
- **Special Cause** variation (signal) is uncontrolled variation. This variation is caused by unique disturbances or a series of them. These may be a one-time event or a permanent process change.
    - A process is ***out-of-control***, ***unpredictable***, and ***unstable*** when special cause variation is occurring.
    - The cause of the variation may be known or unknown. The amount of variation may be large or small.
    - Special cause is not always bad – some special causes improve the process (like increased sales). If the cause is bad, seek ways to change some higher level process to prevent that special cause from recurring.
    - If special cause dominates, isolate and address the special root causes. Do not make fundamental changes to the process. Work to get very timely data and immediately search for cause when the control chart gives a signal. Ask "What *happened* (in that period)? Is it likely to continue or re-occur?"
    - Always identify/document special cause (if known) on your charts with a comment.





Plotting the data on a control chart is the best way to identify whether the variation is due to common or special causes. **Note**: The data must be in time series order for the control chart to be effective.

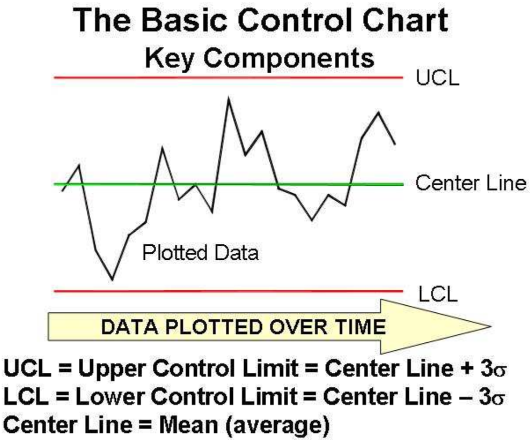
- **Structural Variation** is variation that is part of the process but looks like a special cause when plotted on a control chart.
    - There are **two forms** of structural variation:
        - Structure over time (e.g. seasonality)
        - Structure across space (e.g., consistent differences between cross-web positions, cavities on an injection molder, etc.). I-MR-R/S (Between /Within) is often the proper chart for this case. This is especially true in cases using web processes.
    - There are **two ways to deal** with structural variation:
        - Remove the structure if it makes sense. This requires change to the process (e.g. change policy to reduce end of year effects). Sometimes structure is desirable (e.g. consistent sales increase) so no change is needed.
        - Model the structure and remove its effect by using a tool like BP Chart to see trends or seasonality. This does not reduce actual process variation. It allows better sensitivity to other sources of variability, improving the chart's effectiveness. See your BB or coach for assistance with these. BP Chart is available for downloading from the 3M Six Sigma website.

Control Charts

Control charts are useful to track process statistics over time, to detect the presence of special causes, and to provide a baseline or initial capability for a process. There are two primary uses for control charts:

- **Diagnostic** is used when the goal is to understand the current process. Crucial during the **Measure** and **Analyze** phases. Data are collected and analyzed by improvement team members on a one-time basis.
- **Monitoring** is done when the goal is to maintain process stability. Crucial during the **Control** phase to ensure the improvements remain in place. Data are usually collected by operations personnel or computers on an on-going basis. **Note**: Processes should be well-diagnosed before monitoring them with control charts.

Control Limits



UCL = Upper Control Limit = Center Line + 3σ
LCL = Lower Control Limit = Center Line – 3σ
Center Line = Mean (average)

The control limits on a control chart are based on statistical theory. They represent the limits of common cause variation. They represent a "yardstick" for judging the process stability. If the data are between the control limits in a random pattern, the process is considered stable.

- Approximately 99-100% of the data should fall between the upper and lower control limits.
- **Hint:** The Control Chart uses a "forced" normal distribution standard deviation on the data even if it is not. If the data is normal, the standard deviation used to calculate the UCL and LCL match the regular standard deviation.
- **Hint**: Control charts that use subgroups (average 2 or more samples – X-bar R) are almost always normal. This is one of the great "powers" of control charts.

Control limits and specification limits (from customer) are completely unrelated!

- Control limits are based on process variation (voice of the process) and do **not** necessarily reflect voice of the customer.
- Control charts answer only one question: "Is the process stable?" (Not: "Is the process meeting customer needs or management goals?")
- A stable, in-control process does not guarantee acceptable results. An unstable, out-of-control process may (temporarily) produce acceptable results. Every process has inherent level of variation, and it *does not know the goals*. If the process cannot meet its goal, we must change the process or change the goal.
- **Hint**: Drawing goal lines on a control chart destroys the emphasis – do not draw goal lines on a control chart! Too easy to react to every point that doesn't meet the goal as if it were a special cause.

Two Ways to Create Control Charts (Minitab or BPChart)

- Control charts can be created with either Minitab or BPChart. BPChart is an Excel-based macro tool created at 3M in the 1990s for plotting I-MR charts of data from business processes. (BP Chart is available on the Six Sigma DMAIC website under "software tools".)
- Advantages of BPChart include:
  - Ease of use – most people know Excel
  - Layouts – Multiple charts on one page
  - Incorporates time-based structure (trends, seasonality)
- Limitation of BPChart – Specialty package – can't do other graphs or analyses.
- Some Six Sigma projects require analysis that only Minitab can do. For monitoring a process (standard I-MR) when project is done, either software package can make standard control charts.
  - To incorporate trends and/or seasonality, use BPChart
  - For other charts and analyses, use Minitab

Types of Control Charts (and When to Use Them)

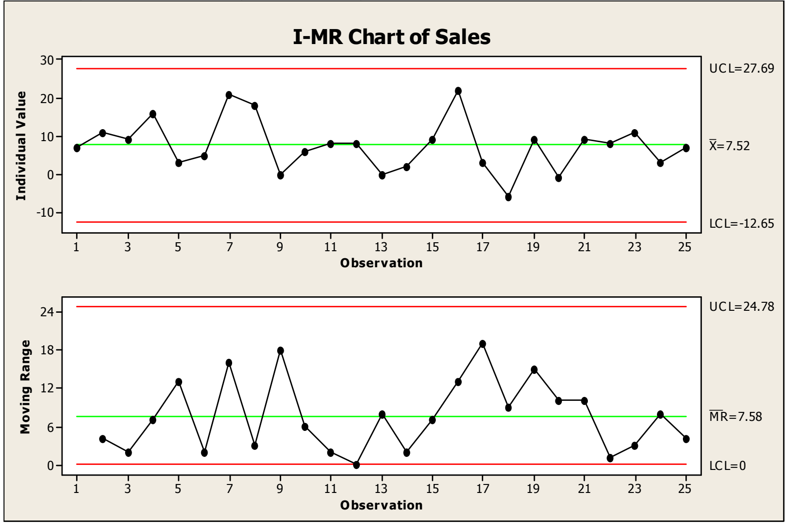
Multiple control charts exist and which one is needed depends on the type of data being analyzed. The typical control chart used on Green Belt projects is the Individuals-Moving Range (I-MR) chart. **Remember:** The data **must be time order** to use control charts!

Variables (Continuous) Control Chart: Used when the output (Y) data is continuous.

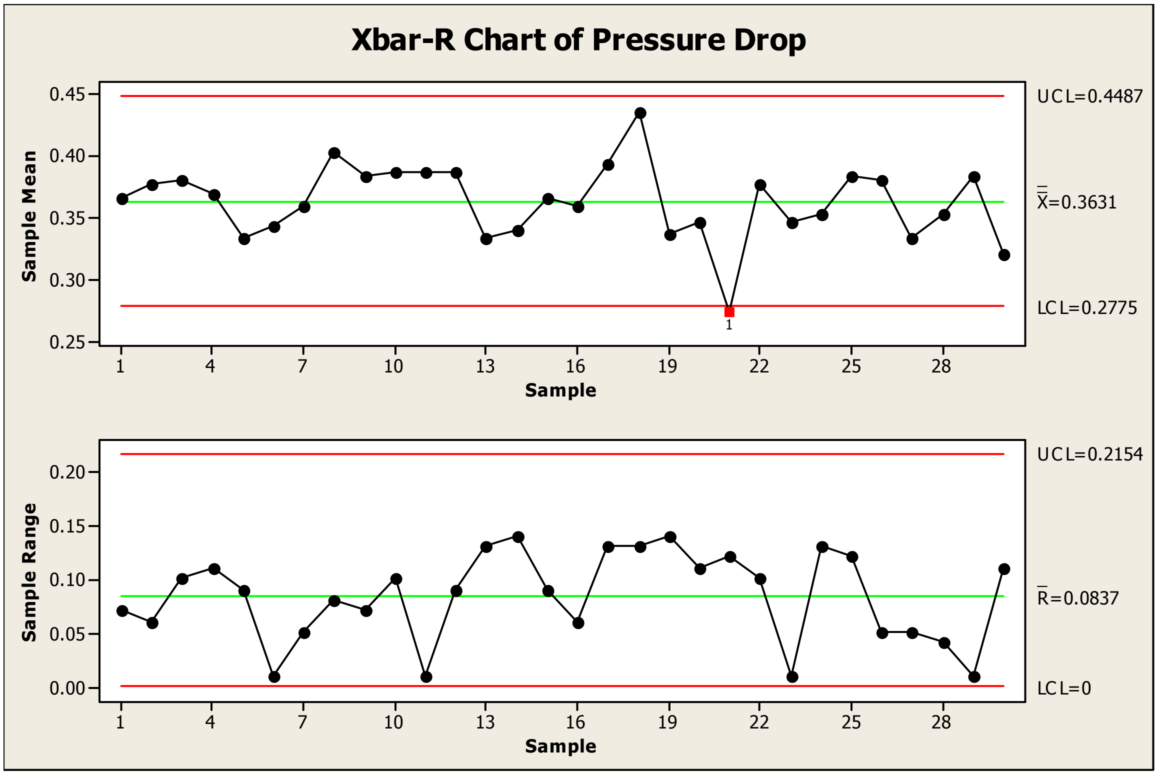
- **Individual and Moving Range (I-MR) Chart –** Control chart for data that are collected for individual observations. Typically used when measurements are continuous output that is homogenous. ***** I-MR is the most commonly used control chart.*****
  - Individuals chart plots every individual point in time order. Assesses stability of process average.
  - Moving Range chart plots the difference between consecutive observations. Assesses stability of process variation – shows short-term variability.

    In Minitab: To see if a process is in control:
    Stat > Control Charts > Variables Charts for Individuals > I-MR > Variable is "Y" (Optional: I-MR Options > Stages > Define Stages is "X")

    Results: If the data points are within the red control limits and a random pattern around the green average line, the process is in control. A process is considered out of control if a point exceeds a control limit. This will suffice for detecting special causes in most cases. Minitab offers additional rules to increase the chart's sensitivity to special causes. See your Black Belt or Six Sigma Coach if you think you need to use these rules.

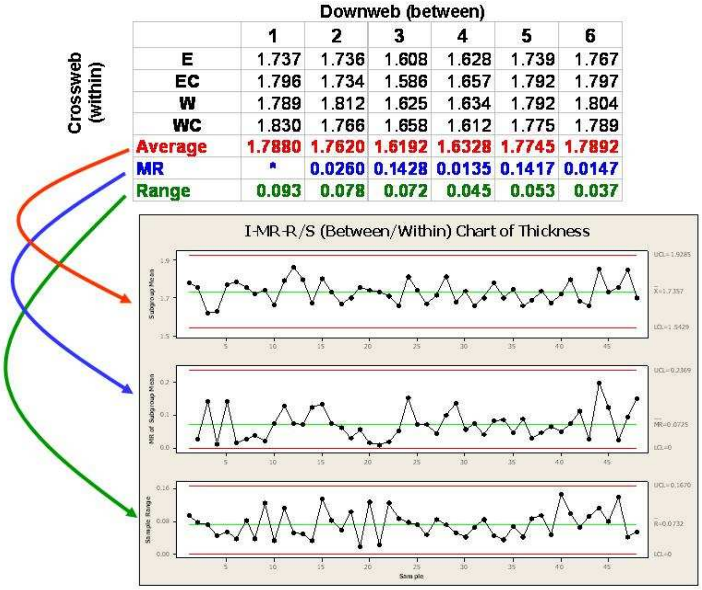


- **X-Bar R –** Control chart for data that are collected in subgroups (where time between groups is longer than time within groups – e.g. 3 samples per hour).
    - X-bar chart plots the average of the subgroup. Evaluates consistency of process average.
        - **Hint:** All samples in a subgroup must be representative of the process independently. If this is not true the variation represented on the chart will over or under estimate the true process variation.
    - R-chart plots the range of the subgroup. Evaluates consistency of process variation.
    - ***In Minitab:*** To see if a process is in control:
      Stat > Control Charts > Variables Charts for Subgroups > Xbar-R > All observations for a chart are in one column: Select Y, Subgroup sizes: Enter size of subgroup or select from list
      Results: If the data points are within the red control limits and a random pattern around the green average line, the process is in control.

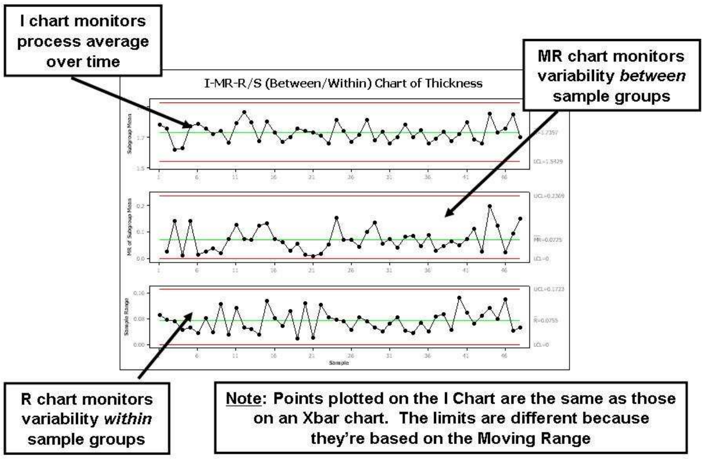


- **3 Chart –** Control chart for **when v**ariation within a subgroup (R charts) does not predict between-subgroup variation
  - Many 3M processes exhibit variation over time (jumbo-to-jumbo, shot-to-shot, batch, etc.) when “logical” subgrouping would be across space (crossweb, cavity, reactor)
  - Control limits for Individual chart need to include within- AND between-subgroup variation. This is accomplished by a 3-chart (monitor within-subgroup variation with an R (or s) chart with subgroup size n).
    - Averaging all n within-subgroup readings into a single number.
    - Treating the within-subgroup averages as individuals.
    - Monitoring variation between subgroups with I/MR chart (limits for the I chart are based on the Moving Range of the subgroup averages).
  - ***In Minitab:*** To see if a process is in control in Minitab:
    Stat > Control Charts > Variables Charts for Subgroups > I-MR-R/S (Between/Within) > All observations for a chart are in one column: Select Y, Subgroup sizes: Enter size of subgroup or select from list

    Results: If the data points are within the red control limits and a random pattern around the green average line, the process is in control.



Crossweb (within)	Downweb (between) 1	2	3	4	5	6
E	1.737	1.736	1.608	1.628	1.739	1.767
EC	1.796	1.734	1.586	1.657	1.792	1.797
W	1.789	1.812	1.625	1.634	1.792	1.804
WC	1.830	1.766	1.658	1.612	1.775	1.789
Average	1.7880	1.7620	1.6192	1.6328	1.7745	1.7892
MR	*	0.0260	0.1428	0.0135	0.1417	0.0147
Range	0.093	0.078	0.072	0.045	0.053	0.037



I chart monitors process average over time

MR chart monitors variability *between* sample groups

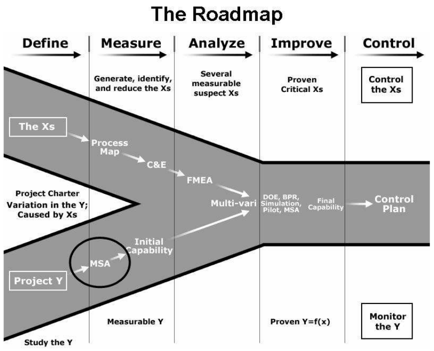
R chart monitors variability *within* sample groups

Note: Points plotted on the I Chart are the same as those on an Xbar chart. The limits are different because they’re based on the Moving Range

Attributes Charts: Used when the Y is in discrete groupings. (See Black Belt or Coach)

- np-chart, p-chart, u-chart, c-chart

H. Measurement Systems Analysis (MSA)



We need to determine whether the existing project Y data and the way we measure it is "good enough." Is the available data suitable for the project? Are we measuring the right thing? Is the data trustworthy? Can we consistently get the same results?

Process variation affects how our products and services appear to our customers. **Measurement variation** affects *our perception* of process variation. Six Sigma depends upon data both to understand the process and to measure improvement, so we will not be successful if the data is not reliable.

Measurement Systems Analysis (MSA) Purpose:

- Identify the right data for the process measurement.
- Understand and eliminate variation due to how the process is measured (through audits, gage R&R and/or attribute agreement studies).

Measurement Systems Analysis (MSA) Goals:

- Correct and valid data are identified for project analysis
- Process can be consistently measured

Issue 1: Data Integrity

Available data might not have been collected with your purpose in mind. You need to determine if the right aspects of the process are captured in the available data. For example, if you are measuring cycle time for a process, does the available cycle time data start and stop at the same points that your charter scope includes?

Data Integrity – Checklist of Questions to Answer

- ☐ What type of data is it?
- ☐ Is available data usable? If not, can it be made usable?
- ☐ Is data suitable for project?
  - o Is recorded data what we meant to record?
  - o Does it contain the information that was intended?
  - o Does the measure discriminate between items that are different?
  - o Does it reliably predict future performance?
  - o Does it agree with other measures designed to get at same thing?
  - o Is the measure stable over time?
- ☐ Is data trustworthy?
  - o How can data be audited?
- ☐ Is the "right" aspect of the process being measured? Don't want just the available data, want the **right** data. The data can be from a very reliable source, but isn't exactly what you need for your project. For example, is income the "right data" for net worth?

Issue 2: Data Reliability

Once we have the right data we must determine our ability to measure it using statistical tools. Variation exists in every process. The question is how much of the variation is caused by **how** the data is collected. The key question on data reliability: *Is the measurement system producing "good" data?*

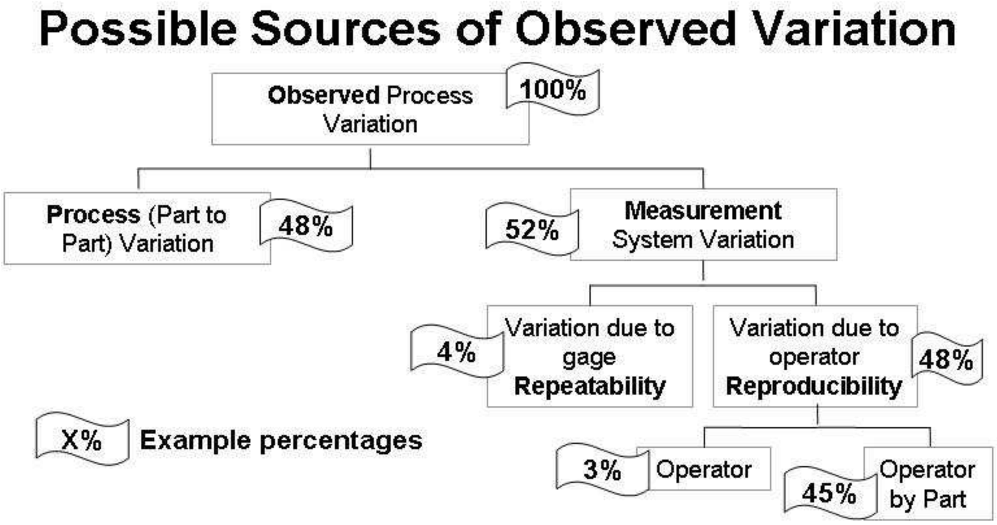
- **Hint:** Study variation of Project Y (output) measurement system first, then focus on measurement system for critical X's (inputs) only

Data Reliability – Checklist of Questions to Answer

☐ How big is the measurement error?
☐ What are the sources of the measurement error?
☐ Is the measurement system stable over time?
☐ Is it capable for this study?
☐ How do we improve the measurement system?

$$\sigma^2_{\text{Observed}} = \sigma^2_{\text{Process}} + \boxed{\sigma^2_{\text{Measurement System}}}$$

Focus on this piece



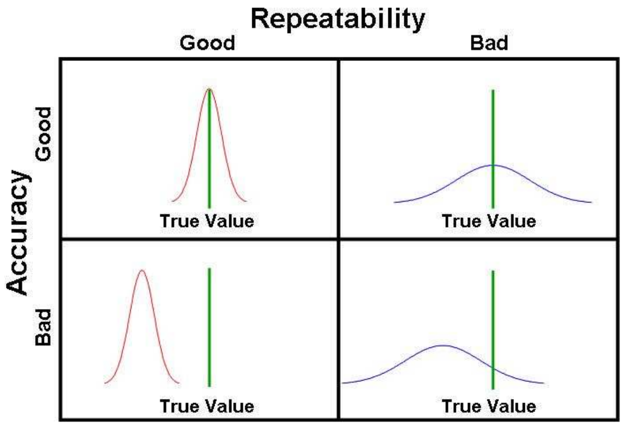
Possible Sources of Observed Variation

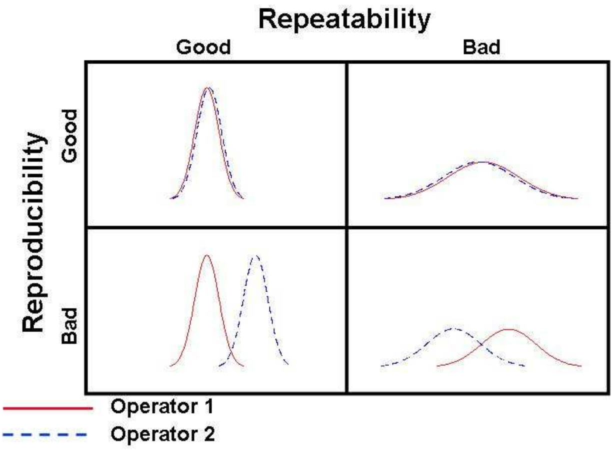
Data Reliability – Terminology

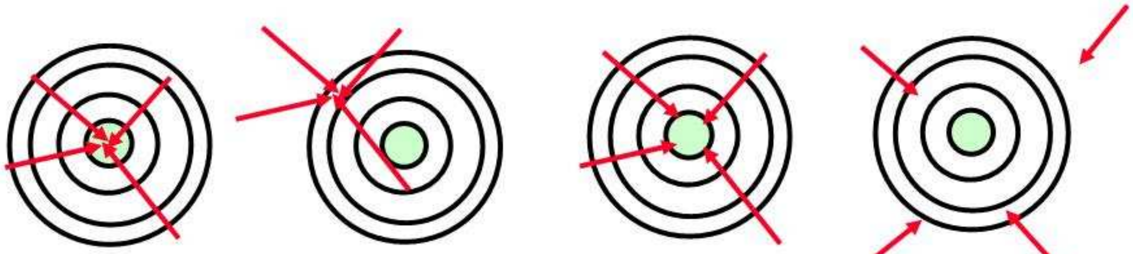
- ***Resolution*** – Number of decimal spaces needed to be measured by the system. Increments of measure should be about one-tenth of width of product specification or process variation. Example of two levels of resolution: 1 inch versus 1.2 inches.

- ***Accuracy*** – Difference between measurements and true value.
  - ***Bias*** – Comparison of the average of all data points to the true value required by the customer. Example of an inaccurate process: process average is 2.5 hours, customer requirement is 7 hours. Bias is difference average and true value: example – between 7 hours and 2.5 hours which equals 4.5 hours. Must have a reference or calibration standard to assess accuracy. Accuracy is dynamic; without calibration it will deteriorate over time!
  - ***Stability*** – Consistency of process over time.

- ***Precision*** – Excess variation in multiple measurements of same part with same device.
  - ***Repeatability*** – Repeated measurements by the same variable are consistent under same conditions (same operator, same unit, same environmental conditions, short-term). Typically identifies an equipment issue. Example: Same person doing the same activity gets the same results.
  - ***Reproducibility*** – Repeated measurements by the different variables are consistent under same conditions. For example, different people using , same instrument, measuring identical characteristic. Typically identifies an issue with operators. Example: Two different people doing the same activity get the same results.







Accurate and Precise

Precise but not Accurate

Accurate but not Precise

Not accurate nor precise

Data Reliability – Ways to Verify

Use one or more of the following methods to determine if the measurement system is accurately measuring the process and if you can rely on the data. Check with Black Belt or coach for the appropriate tool(s) for your project.

- **Audits**
  - Used to verify reliability of data from most **business processes**. The team must find a way to verify the data with a second, independent source to assure ourselves the data is a clear and accurate record of actual characteristics or events of interest.
  - Used to measure business indices, numbers from databases (sales, costs), dates or times (cycle time projects). Basic goal is very simple: Is data *correct* and *valid*?
- **Gage R&R Studies**
  - Used to measure consistency of **continuous** data by comparing individuals to themselves and each other.
  - Used to measure physical properties (product quality, thickness, viscosity) or rating scales (Real-Win-Worth, Charter metric).
- **Attribute Agreement Analysis**
  - Used to measure consistency of **discrete** data by comparing individuals to themselves and each other.
  - Used when assigning yes/no, pass/fail, or when assigning items to categories (reasons for customer returns; type of defect).

Audits

- Used to verify reliability of data from most **business processes**. The team must find a way to verify the data with a second, independent source to assure ourselves the data is a clear and accurate record of actual characteristics or events of interest. Can be used to measure business indices, numbers from databases (sales, costs), dates or times (cycle time projects). Basic goal is very simple: Is data *correct* and *valid*?
- For example, a team could compare two different new product sales reports to determine if the same products are listed on both reports. Then, other analysis tools can be used like Regression.
- Audits must be independent of data collection, processing and reporting system we are assessing. Compare results from "normal" data system with data from a second, independent source. Do we get same answer from both sources?

Audit Methods

- For most organizations, data is kept in computer databases (consider involving an IT representative). Some portions (if not all) of data processes are already being checked automatically for data integrity – Check Super Ys for MSA replication opportunities.
- Determine acceptance criteria in advance. For example:
  - Errors on less than X% of samples
  - No errors more than Y units (or Y%) away from the correct value
- No "one size fits all" approach to data integrity auditing. Types of audits include:
  - Comparing a computer system to: another computer system, manual reporting system or physical records.
  - Observing a process to verify correct data entry.
  - Looking at the data to find impossible or questionable results.
  - Using surveys to double-check results.

Gage R&R Studies

$$\sigma^2_{\text{Observed}} = \sigma^2_{\text{Process}} + \boxed{\sigma^2_{\text{Measurement System}}}$$

Focus on this piece

- Used to measure consistency of **continuous** data by comparing individuals to themselves and each other. Can be used to measure physical properties (product quality, thickness, viscosity) or rating scales (Real-Win-Worth, Charter metric).
- For example, if the measurement system involves estimating the dollar value of an opportunity, a study can be done to see how consistently person A estimates a particular opportunity more than once. The study also analyzes how similar A and B's estimates are to each other.
- Gage R&R metrics are:
  - *P/T Ratio = Precision to Tolerance Ratio*

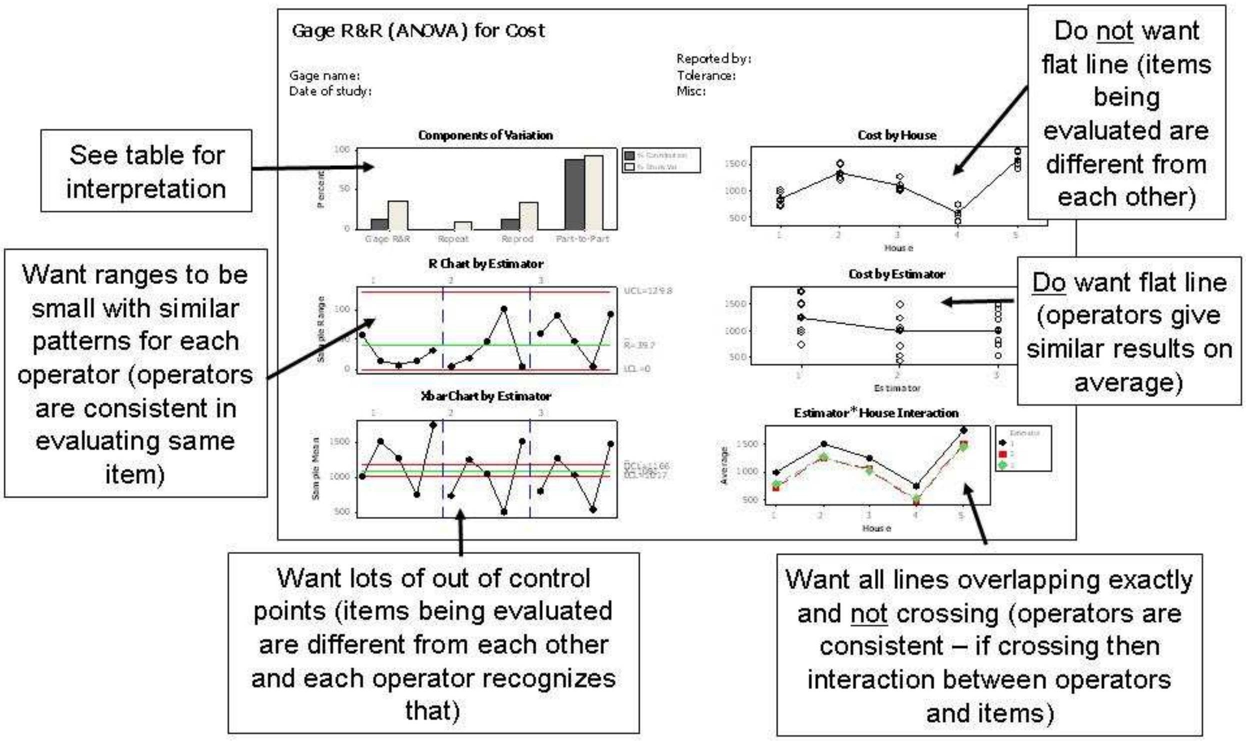
    $$\boxed{P/T = \frac{6*\sigma_{MS}}{Tolerance} = \frac{6*\sigma_{MS}}{(USL - LSL)}}$$

    - **What is it?** Compares Measurement System Variability to the Product Specification (customer specifications – USL and LSL). Includes repeatability and reproducibility.
    - **What question does it answer?** How much of the product tolerance (USL - LSL) is taken up by measurement error?
      ***** Must have customer (or product specifications at least) to get the P/T ratio!*****
  - *% R&R (%SV = %Study Variation)*

    $$\boxed{\%R \,\&\, R \text{ or } (\%SV) = \frac{\sigma_{MS}}{\sigma_{Total}} \times 100}$$

    - **What is it?** Compares the Measurement System Standard Deviation to the Total Observed Standard Deviation (process and measurement system together)
    - **What question does it answer?** How much of total observed variation is taken up by measurement system?
    - **How is it calculated?** Calculated based on the standard deviation of the measurement system and the total variation.
- Conduct a Gage R&R study to quantify repeatability and reproducibility components of measurement variability and estimate %R&R. May also obtain P/T ratio if process specifications are available.
  - Need the following:
    - 2-3 operators, spanning the capabilities or experiences
    - 5-10 samples, spanning the normal range of the process
      - **Hint:** (number of samples) X (number of operators) > 15 (before repeating and no duplicates)
  - Each sample is measured 2-3 times by each operator in a random order with time between the evaluations for each operator.
    - **Hint:** If conducting a destructive test, it may be best to use 5-10 batches with only 2 replicates (or samples within each batch) in order to minimize confounding with sample. Also, the samples need to be as "identical" as possible.
  - See your Black Belt for more information on sample sizes and setting up a Gage R&R study
- ***In Minitab:*** To analyze the Gage R&R study in Minitab:
  Stat > Quality Tools > Gage Study > Gage R&R Study (Crossed) > Part numbers: Select item being studied, Operators: Select operators, Measurement data: Select results of study, Click on Options > Study variation: Enter the number 6, Process tolerance: If known, enter the range of the customer specifications
  Results: See table and graph on next page.

Classification	P/T	% SV or % R&R	% Contribution
Best Case	< 10%	< 10%	< 10%
Acceptable	< 30%	< 30%	< 30%
Unacceptable (unless destructive)	> 30%	> 30%	> 30%
Unacceptable when destructive	> 50%	> 50%	> 50%



See table for interpretation

Want ranges to be small with similar patterns for each operator (operators are consistent in evaluating same item)

Do not want flat line (items being evaluated are different from each other)

Do want flat line (operators give similar results on average)

Want lots of out of control points (items being evaluated are different from each other and each operator recognizes that)

Want all lines overlapping exactly and not crossing (operators are consistent – if crossing then interaction between operators and items)

Attribute Agreement Studies

- Used to measure consistency of **discrete** data by comparing individuals to themselves and each other. Can be used when assigning yes/no, pass/fail, or when assigning items to categories (reasons for customer returns; type of defect).
- For example, if the measurement system involves classifying customer complaints into categories, a study can be done to see how often person A agrees with himself in categorizing the same complaints, and how often person A and B agree with each other.
- Attribute (discrete) data contains less information than continuous data, but sometimes it is all that is available. Therefore, you must be even more demanding about the integrity of attribute measurement systems.
- Goals of attribute agreement studies are similar to MSA goals for continuous data systems. In attribute MSA we are getting similar information, but in a different approach with new metrics.
- Attribute agreement metrics are:
  - *% Agreement – how many agreements did you have out of all possibilities (samples)?*
    - Agreement within appraisers (repeated trials - repeatability)
    - Agreement between appraisers (reproducibility)
    - Agreement of appraisers with expert or known standard (accuracy)
  - *Kappa – level of agreement after random chance is removed (how much better than random chance?)*
    - within appraisers
      - Individual Kappa for category – represents how consistently each appraiser rates same samples over multiple trials in one category
      - Overall Kappa – for each appraiser represents that appraiser's consistency across all categories
    - between appraisers
      - Individual Kappa for category – represents how consistently all appraisers categorized samples in that category
      - Overall Kappa – represents study-wide agreement (across appraisers and categories)
    - appraisers with expert
      - Individual Kappa for category – represents how consistently each appraiser rates same samples in one category compared to expert
      - Overall Kappa – represents study-wide agreement (across appraisers and categories) to expert
    - **Note:** If there is substantial agreement, there is the possibility the ratings are accurate. If agreement is poor, usefulness of ratings is extremely limited.

- Conduct an attribute agreement study to quantify repeatability and reproducibility components of measurement variability and estimate Kappa.
  - Need the following sample:
    - 2-3 operators, spanning the capabilities or experiences
    - 30-50 samples, spanning the normal variation and extremes of the process (Majority should be from 'gray' areas. Remainder should be clearly good or clearly bad)
  - Method to conduct the study:
    - Select 2-3 people who normally conduct the assessment.
    - Randomly provide samples to one person (without indicating which sample is which) and have the person rate each of the items.
    - Once first person has reviewed all items, repeat with remaining people.
    - Once everybody has rated each item, repeat steps above for a second trial.
    - **Note**: All possible combinations of appraisers, items, and "trials" should be represented:
      - Each appraiser must examine all of the items.
      - Each appraiser must examine those items the same number of times (trials).
    - **Note:** Requirements for use:
      - Units to be measured are independent from one another.
      - Raters inspect and classify independently.
      - Rating categories are mutually exclusive and exhaustive.

- ***In Minitab:*** To analyze the Attribute Agreement study in Minitab:
  Stat > Quality Tools > Gage Study > Attribute Agreement Analysis > Attribute column: Select result of study, Sample: Select item being studied, Appraiser: Select operators, Known standard/attribute: Select expert's ratings, Click on Results > Choose In addition, kappa and Kendall's (ordinal data) coefficients
  Results: See table below

Classification	Kappa
Perfect agreement	1
Excellent	>0.90
Acceptable – Some improvement warranted	>0.70
Unacceptable – Measurement system needs attention – significant effort required	< 0.70
Random agreement – flip a coin	-1 to 0.0

Attribute Measurement Systems Improvement Techniques

- Visual aids
- Operational definitions
- Cleaning up category codes
- Sense multipliers (devices to improve human senses)
- Masks / templates (block out unimportant information)
- Checklists
- Automation
- Reorganization of work area

MSA Tips

- See your Black Belt for more information on sample sizes and setting up a Gage R&R and/or attribute agreement studies.
- To audit business data, audit documents must be produced to show the relevance and correctness. Relevance must always be checked, especially for relative values such as square meters per time unit or material, etc
- In the Gage R&R analysis – repeated measurements on the same part must be possible. When destructive test methods are used, homogeneous material must be used.
- To validate data from databases use known test inputs or compare with original data.
- A plausibility check is useful for large amounts of data, whereby the data for each variable are sorted by size. It is important to return the data to their original state after the test.
- All MSA studies need to have precisely defined test conditions.

Common Process MSA Pitfalls

- Assuming that corporate database information is automatically good. The data may not have been collected correctly or with your purpose in mind.
- Not conducting MSA until very late in the project.
- Measuring equipment does not have a high enough resolution.
- Assuming that projects on business processes (non-manufacturing) don't require an MSA. Many business processes may not have a measurement system at all and will require the project team to create one.

MSA Checklist

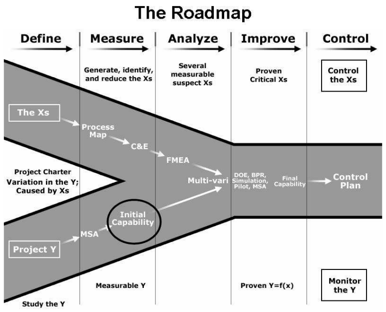
☐ Have you picked the right measurement system? Is this measurement system associated with either critical inputs or outputs?
☐ What do the precision, accuracy, and stability look like?
☐ What are the sources of variation and what is the measurement error?
☐ What needs to be done to improve this system?
☐ Have we informed the right people of our results?
☐ Who owns this measurement system?
☐ Who owns trouble shooting?
☐ Does this system have a control plan in place?
☐ What's the training frequency? Is that frequent enough?
☐ Do identical systems match?
☐ What are the major sources of measurement error?
☐ Did you conduct an MSA on the project Y's and all critical inputs (X's)?
☐ How much measurement error exists compared to the process variation (% R&R)?
☐ How much measurement error exists in comparison to the specifications (%P/T)?
☐ Is the measurement system acceptable for the process improvement efforts? If not, what actions should be taken?
☐ How were the samples chosen? Do they adequately cover the entire process?

Next Steps

Complete remaining tasks in Measure Phase (Process Map, C&E Matrix, Capability Studies) and move onto Analyze Phase with the FMEA.

Lessons Learned

I. Capability Studies



Capability Studies Purpose:

- Compare voice of process to voice of customer.
- Determine the stability of the process.
- Determine whether the process is meeting the project goals (ideally customer needs).
- Establishes a baseline for process Y(s). (How is process performing today? How much does it need to improve to reach project goals?)
- Identify what kind of improvement strategy is needed.

Capability Studies Goals:

- Initial process capability documented.
- Identification of type of improvement strategy needed.

Steps to Follow

Step 1 – Determine stability by gathering initial data and plotting in time order

- **Assemble data** from recent history and record the data in time order. Ideally, collect 20-25 points, although this may not be possible for all processes, depending upon the frequency of data.
- **Create a control chart** (such as an I-MR or Individuals chart) to see if the process has common or special cause variation. (See "Statistical Process Control" for more information.)
    - *Common Cause* – Normal/random process variation, noise.
    - *Special Cause* – Unusual, unpredictable events. Causes may be one-time events or permanent changes to the process.
- A process is "stable" if it has only common cause variation – all data points inside the control limits (red lines) on control chart and no obvious trends.

Step 2: Determine improvement strategy

- If ***special*** causes dominate:
    - Ask: *"What happened at the time of the special cause?" "Is it likely to continue or re-occur?"*
    - Identify and address the root cause that created the change.
    - Don't redesign the entire process while special causes still exist. First, address special causes, and then determine if a redesign is needed.
- If ***common*** causes dominate:
    - Ask: *"What is happening each time we do the process?"*
    - Analyze all data (not just ones that didn't meet the goal) and study potential sources of variation.
    - If only common causes exist, but goals aren't being met, entire process may require change.

Step 3: Evaluate capability – the ability to meet the customer requirements

- Compare baseline results with customer requirements (project goals, customer specifications, etc). (**Hint:** Make sure your metric and the customer use the same units.) Use one of the following tools to do the comparison.
    - **Attribute (Discrete) data** – calculate Defects Per Unit (DPU)
    - **Continuous data** – calculate capability indices
- Determine what is needed to meet customer requirements (**Important:** Verify customer specifications are real):
    - Shift the process average
    - Reduce total variability

Attribute (Discrete) Data Capability

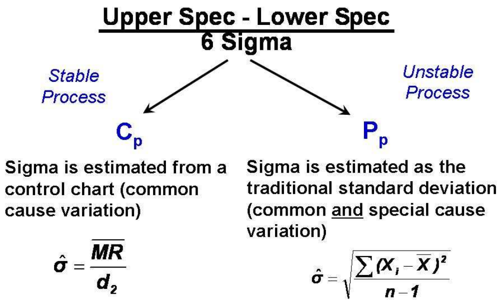
- When the data are attribute or discrete, the capability is determined by counting the number of defects (as defined by the customer) in each unit.
- **Step 1: Define the unit** – The physical output from the process that is inspected, evaluated, or judged by others to determine "suitability for use." Typically something delivered to customers or users. Defined by a starting and stopping point for continuous flow products or services.
- **Step 2: Define the defect** – anything that does not meet a critical customer requirement, does not meet an established standard, or causes unwanted variation.
- **Step 3: Calculate the number of Defects per Unit (DPU)**

$$\boxed{\text{DPU} = \frac{\text{Total \# of Defects}}{\text{\# of Units}}}$$

  - Count all individual defects (or errors) on each unit (can also be calculated for individual defect types – then can identify which defect type is creating largest loss to RTY).
  - DPU can be graphically represented using Pareto Charts
  - **Note**: Defects versus Defectives:
    - A defective unit is any unit containing a defect. There can be multiple defects in one defective unit. Reducing defects improves RTY and leads to breakthrough process performance.
    - Defectives are a result of defects. It is impossible to reduce defectives without reducing the number of defects. Focusing on defectives often leads to costly inspection and rework.
  - DPU does not take process complexity into account
    - Customer call capability = 0.16 DPU
    - Invoice writing capability = 0.68 DPU
    - Is it fair to compare these two processes? Is it important?
  - Defects per Million Opportunities (DPMO) is a metric that incorporates process complexity.
    - Can be very impractical because it is often very difficult to define an opportunity.
    - Only use DPMO if very important to compare two processes of different complexity.
  - DPU is the preferred attribute capability metric. It measures defects, not defectives. It can help prioritize project issues (Pareto defects).

Continuous Data Capability

- When the data are continuous, the capability is determined comparing the capability of a process (voice of the process) to the specification limits (voice of the customer). The data must be in time order.
- Two types of capability indexes are used:
  - **C = Process Capability** - what the process potential is given a stable process. (Standard deviation estimated from Moving Range or pooled standard deviation – represents common cause variation only). Measure of what the process performance is short term.
  - **P = Process Performance** - what has happened, not necessarily what will happen. (Standard deviation estimated from the traditional formula – includes both common and special cause variation). Indicates likely process performance long term.



$$Cp = \text{Capability} = \frac{\text{Voice of Customer}}{\text{Voice of Process}} = \frac{\text{Total Tolerance}}{\text{Control Limits}} = \frac{USL - LSL}{6s}$$

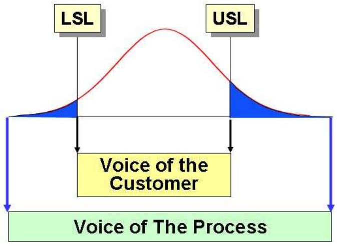
C_p = Capability for Stable and Centered process (on target)

- Want C_p to be greater than one (bigger *is* better). $C_p > 1$
- C_p only accounts for ***common cause*** *variation*

C_{pk} = Capability for Stable process (not necessarily centered)

- Cpk penalizes you for being ***off target***.
- If $C_p > C_{pk}$, then ***off target***.
- If $C_p = C_{pk}$, then ***on target.***

$$C_{pk} = \text{Min}\left(\frac{\bar{X}-LSL}{3s}, \frac{USL-\bar{X}}{3s}\right)$$



P_p = Capability for Unstable and Centered process

$$Pp = \text{Capability} = \frac{\text{Voice of Customer}}{\text{Voice of Process}} = \frac{\text{Total Tolerance}}{\text{Control Limits}} = \frac{USL - LSL}{6s}$$

- Want P_p to be greater than one (bigger *is* better). $P_p > 1$
- If $C_p > P_p$, then ***unstable process*** or one with ***special cause variation*** (in addition to the *common cause variation*).

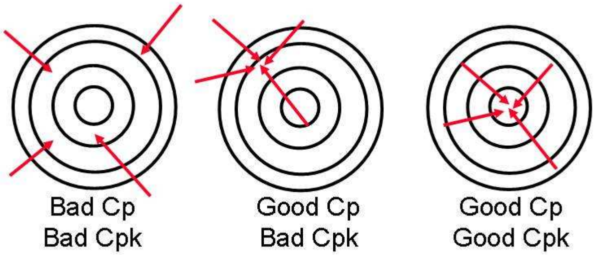
P_{pk} = capability for Unstable process (not necessarily centered)

- P_{pk} **penalizes** you for being ***off target***.
- If $P_p > P_{pk}$, then ***off target.***
- If $P_p = P_{pk}$, then ***on target.***

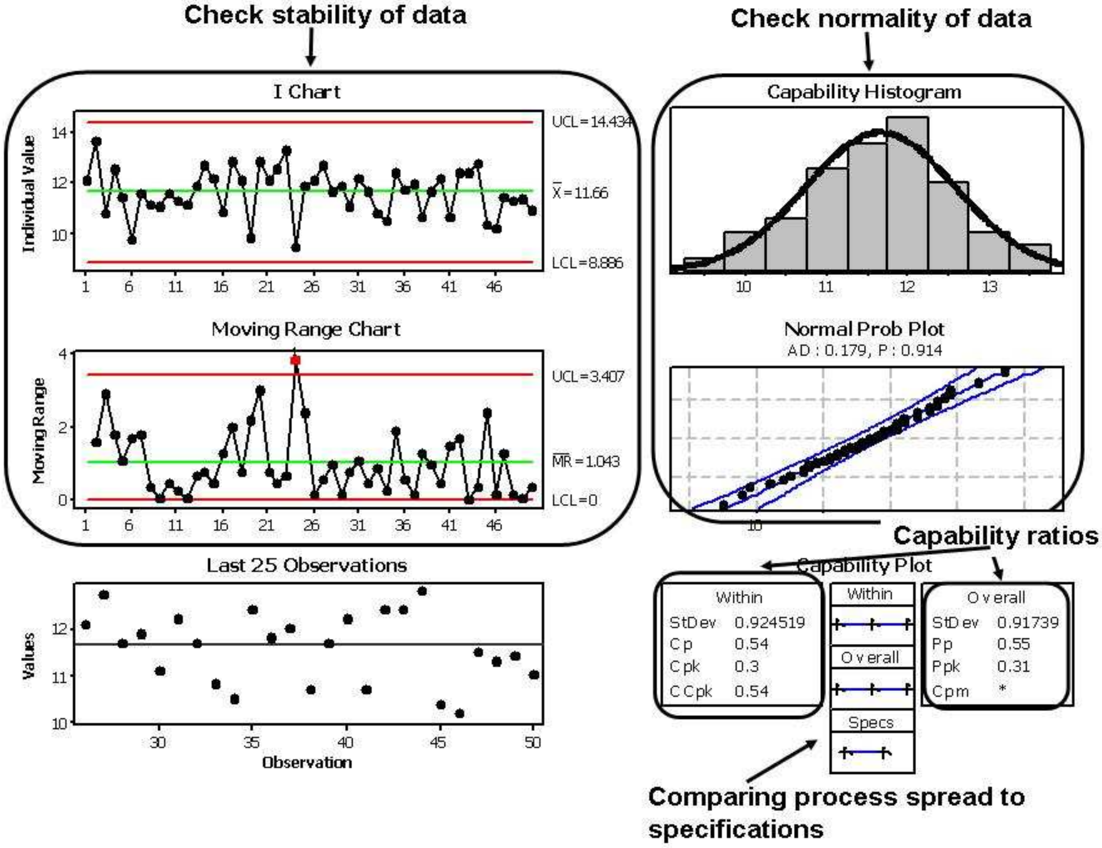
Variability

Process Mean	Common Cause Only	Special & Common Causes
Center of Specs	Cp	Pp
Current Value	Cpk	Ppk

If Indices are:	$C_p = C_{pk} = P_p = P_{pk}$	$C_p > C_{pk}$ $C_p = P_p$	$C_p > P_p$ $C_p = C_{pk}$ $P_p = P_{pk}$	$C_p > P_p$ $C_p > C_{pk}$ $P_p > P_{pk}$
Then process is:	Centered (On Target) and Stable	UNcentered (Off Target) and Stable	Centered (On Target) and Unstable	UNcentered (Off Target) and UNstable
Report:	C_p and C_{pk}	C_{pk} only	P_p only	P_{pk} only



- ***In Minitab:*** To analyze the Capability Study in Minitab:
  Stat > Quality Tools > Capability Six Pack > Normal > Single column: Result of study, Subgroup Size: Typically the number 1, Lower Spec: Enter value, Upper Spec: Enter value
  Results: See chart below.



Capability Studies Tips

- C_p, C_{pk}, P_p, and P_{pk} **estimate the "truth."** You will never know the true P_{pk}; it is based on *estimates* of μ and σ. The estimates will change as new data are collected.
- Data come from a **stable process** – If not, performance metrics (P_p, P_{pk}) are only accurate measure of current state of process. C_p, C_{pk} are just "best case" scenarios.
- **Data normally distributed** – If data are not normal because they are not stable, lack of stability is real issue and non-normality is not an immediate concern. If data are stable and non-normal, data may need to be transformed (see a Six Sigma Coach).
- Best to control chart capability indices over time rather than relying on a single number.
- For a process to be considered Six Sigma:
  - $C_p = 2.0$
    - If stable, voice of process is half the size of voice of customer
    - If process is centered, mean is 6σ away from either specification limit
  - $P_{pk} = 1.5$
    - Accounts for 1.5σ shift and drift
    - **Note**: Achieving a 6σ level of capability is not necessarily the goal of every project
- Capability metrics (with **no** customer specification) – baseline of process
  - Mean, Standard Deviation, DPU
- Capability metrics (**with** customer specification) – baseline of compared to expectation/requirements
  - C_p, C_{pk}, P_p, P_{pk}

Common Capability Studies Pitfalls

- Lacking adequate "customer" specifications that do not truly represent the customer needs (end-of-roll samples, averaging multiple samples, how does customer define a unit?) or specifications that are set internally (+/- 3σ – maximum $C_{pk} = 1.0$).
- Trying to improve numbers instead of improving process by manipulating numbers, changing specifications, etc…
- Trying to see Cpk when it may not be applicable due to an unstable process.
- Overemphasis on one number from a single study to measure the process (short-term vs. long-term, tracking capability over time).
- Putting too much focus on data points that do not meet customer requirements when the overall process is stable (has only common cause variation). Often happens when a goal is on a control chart.
- An "in control" or stable process is not necessarily good enough. While you may still need to improve this process, your improvement strategy will be different than it might for an out-of-control process.
- Having a stable but non-normal process. May need to do a transformation. See your Black Belt or coach.

Capability Studies Checklist

- Initial Capability:
  - ☐ What are long and short-term process capability values?
  - ☐ How does the process compare to the customer’s perspective of performance?
  - ☐ Is there a significant opportunity to improve beyond current levels (e.g. how large is the gap between C_p and P_{pk})?
  - ☐ What are the definitions of defects and opportunities?
- Baseline Data:
  - ☐ How much data or what time period was used to determine the baseline capability?
  - ☐ What variables were evaluated?
  - ☐ Are they stable?
  - ☐ Are there explanations for out of control signals?
  - ☐ How long was the process monitored to determine stability?
  - ☐ Have you captured samples of data that truly reflect the normal process?
- Final (Improved) Capability:
  - ☐ How much data or what time period was used to determine the baseline capability?
  - ☐ What variables were evaluated?
  - ☐ Are they stable?
  - ☐ Are there explanations for out of control signals?
  - ☐ How long was the process monitored to determine stability?
  - ☐ Have you captured samples of data that truly reflect the normal process?
  - ☐ Do you have six data points indicating a sustainable “special cause” created by your project?

Next Steps

Complete remaining tasks in Measure Phase (Process Map, C&E Matrix, Measurement Systems Analysis) and move onto Analyze Phase with the FMEA.

Lessons Learned

Measure Phase – Completion Checklist

☐ Measurement System Defined (Project MSA Completed)
☐ Baseline Process Capability (Initial Capability)
☐ Process Map Completed
☐ C&E Matrix completed providing prioritized X’s
☐ FMEA completed provide prioritized X’s and theories on failures
☐ Updated Charter
☐ Project Team in Place

IV. Analyze

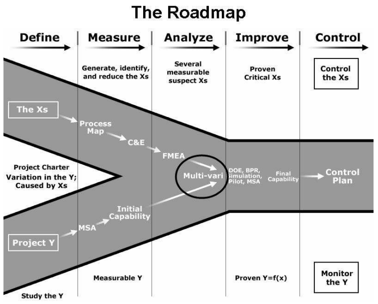
Analyze Phase Purpose:

- To begin learning about the relationships between the X’s and Y’s and identify potential sources of process variability

Analyze Phase Goals:

- Reduce the number of inputs (X’s) to a manageable number
- Determine the presence of noise variables through Multi-Vari Studies
- Plan first improvement activities

A. Multi-Vari Analysis



Multi-Vari Analysis Purpose:

- Collect data and search for “clues” about the inputs (X’s) that have the biggest effect on the output (Y).
- Collect data to support intuition and experience that created C&E and FMEA.
- Discover inputs initially missed on process map, C&E, FMEA.

Multi-Vari Analysis Goals:

- Find the key inputs (X’s) to advance to the Improve phase and avoid wasting time experimenting and controlling unimportant inputs (X’s).

Multi-Vari Analysis is a study of MULTIple VARIables. It is an organized approach to collecting and analyzing data without changing or experimenting with the process. ***Passive data collection***. The three ways to always look at data include: Practical, Graphical, and Analytical.

Cautions with a Multi-Vari Study

- Recall the “Laws of Snapshooting”: beware of looking at only one point in time. Need to study entire process.
- Look at everything that seems pertinent. Go in with an open mind – otherwise you will only see what you expect to see and miss something the process has to tell you.
- Be aware of biases (conscious or unconscious). They limit the way we look at data or situations. Instead let the data tell you what’s important.

Steps to Conducting a Multi-Vari Study

Step 1 – Determine which X’s (inputs) and Y’s (outputs) to study – Must be measurable!

- **Y’s**: primary, secondary and counterbalancing Y’s typically from the charter. May be final process
- **X’s**: prioritized from FMEA (look for Causes of Failure Modes)
  - Use tools to focus study only on suspected critical Xs and potential noise variables (C&E; FMEA – causes of failure modes for high RPNs; control charts and capability studies – Xs that might make common or special cause variation)
- **Noise variables**: Xs that cannot or choose not to control. Important noise variables need to be identified so compensating mechanisms can be put in place. If possible, address these sources of variation early in Improve phase before attempting experiments on currently controlled input variables. Examples:
  - Manufacturing – raw material properties, humidity, temperature, supplier lead time, customer demand;
  - Transactional – economic conditions, customer demand, customer payment policy, competitor actions.

Step 2 – Establish objectives or questions relating specific X's to specific Y's to be answered or supported with data

- Does a specific input (X) influence a specific output (Y)?
- What type of data are inputs and outputs and what graphs/statistics can be used to analyze the data?
- What theories (hypotheses) need to be answered?
- Critical to think about the objectives and the data analysis simultaneously before collecting data.

Step 3 – Identify sources of data for each X and Y (S.H.O.P.) – May need more than one approach to capture all Xs and Ys

Surveys

- May be the only source of data – especially for some business processes
- Data depends on the quality of the survey design – be careful not to ask leading questions
- Can be expensive and time consuming

Historical data

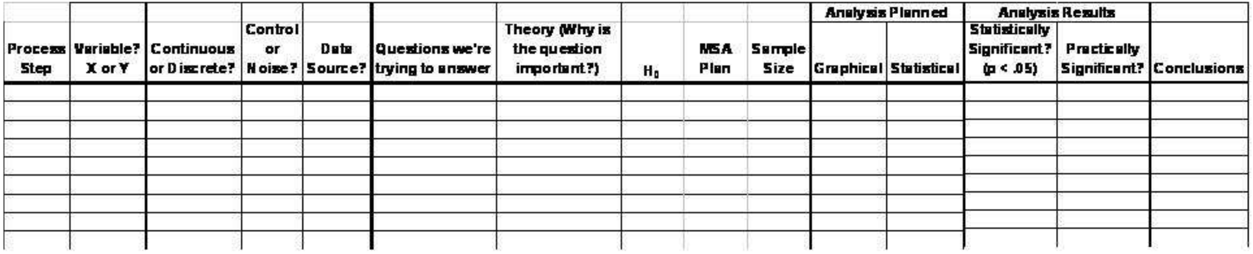
- Least disruptive; can provide quick insights into input (X) and output (Y) relationships
- Generally available, but quality may be questionable if carelessly recorded
- 3M has many systems that collect data. Can provide quick insight into X and Y relationships. Can learn from previous projects' data.
- "Reassembling" historical data can provide new insights. For example: studying last 50 product transfers, reviewing previous new product introductions, product conversions, equipment downtime, equipment installations. Collecting reassembled data may require interviews, surveys, or reviewing old records.
- Cautions:
  - Obtaining and manipulating data may be time consuming
  - May not represent today's process
  - Data not necessarily collected with your objectives in mind – may be missing Xs
  - Integrity can be suspect if information recorded carelessly or has a poor measurement system.

Observe **P**rocess

- Always the best choice, but may be impractical.
- Can plan data collection to meet project needs.
- Can learn more from watching than relying on memories & opinions
- Allows flexibility in data collection. Can observe special causes, pareto sources of variation, and observe Xs causing changes in Y.
- May require new measurement systems or taking more frequent measurements.
- Moderately disruptive – watch for the "Hawthorne effect" (people change what they do because they are being watched)

Step 4 – Plan the data collection

- <u>**S**urveys:</u> Limit questions and include good operational definitions. Choose broad representation of people to survey. Get help designing a good survey from your Black Belt or coach. Also, see section "Survey/Questionnaire Tip Sheet".
- <u>**H**istorical:</u> Entire population or sample? Time period to pull? Can the X's be synchronized with the Y's (Y may be affected by X in an earlier time period)? Organization of data (how and where will the data be inputted)?
- <u>**O**bserve the **P**rocess</u>:
  - Search for sources of variation. Observe the effect of X's on the Y's. May design a noise tree to help identify which noise factors have biggest impact.
  - Plan data collection. Need clear roles & responsibilities (who will collect what data), operational definitions, timing (when to start, how long to observe, how synchronize X's with Y's), copious notes, and prompt data logging (enter as soon as possible to minimize risk of losing or forgetting information).
- Use the Multi-Vari study worksheet to organize data collection and analysis plan (see ubertool).



										Analysis Planned		Analysis Results		
Process Step	Variable? X or Y	Continuous or Discrete?	Control or Noise?	Data Source?	Questions we're trying to answer	Theory (Why is the question important?)	H_0	MSA Plan	Sample Size	Graphical	Statistical	Statistically Significant? ($p < .05$)	Practically Significant?	Conclusions

Step 5 – Run a pilot

- No matter what the data collection method, run a pilot!
- Verify that: you'll get the information you need; X's and Y's are measurable; resources are adequate to collect data; data collection plan is thorough; operational definitions are clear; and data analysis plan will work.
- Things can learn from pilot:
  - Surveys: Questions misleading, biased, or confusing; anonymity issues exist; people surveyed may not have necessary knowledge; survey takes too long; surveyors ask questions differently.
  - Historical and observing the process: Can't synchronize Xs and Ys; identify additional Xs to study; MSA issues exist.

Step 6 – Make necessary changes to plan

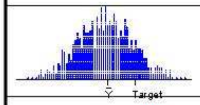
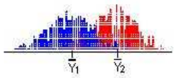
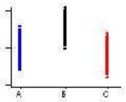
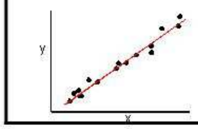
- Update based on the learnings from the pilot. Might include additional Xs needed, reallocating resources, revised or removed survey questions, or clarify operational definitions.

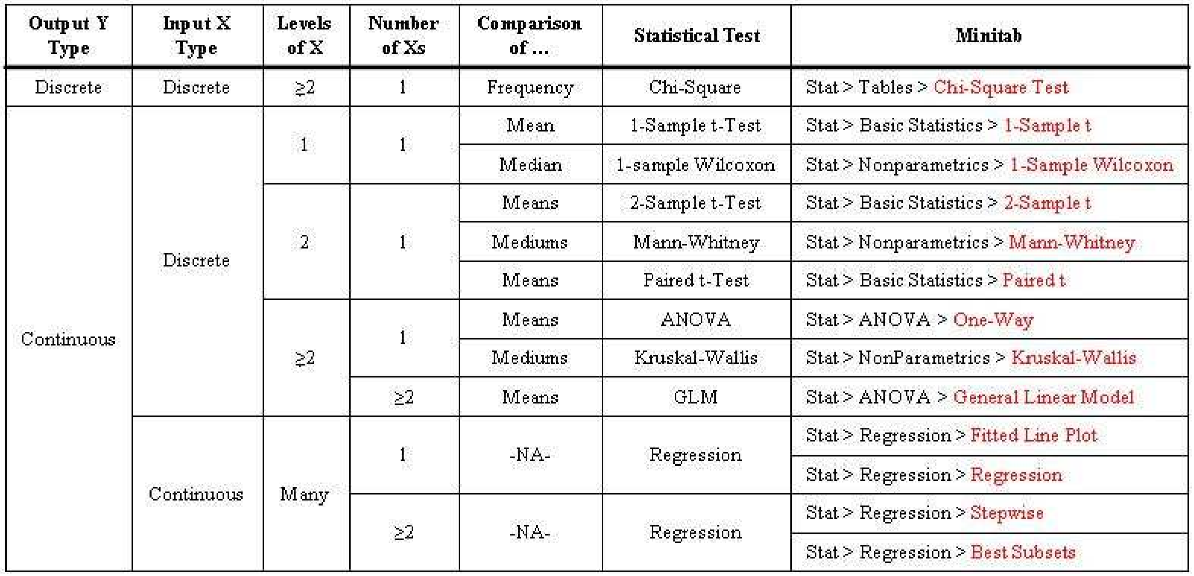
Step 7 – Run study and collect data

- Gather data, log any unusual observations, and format for Minitab. Minitab prefers: list inputs (Xs) 1 per column; list outputs (Ys) 1 per column; add a separate column for capturing text comments. Can enter the data in Excel and then copy to Minitab.

Step 8 – Analyze data

- Graph the data first (using your roadmaps!):
  - Control charts or Time Series plots of Ys and Xs (if there's a time sequence)
  - Boxplots of Y vs. Discrete X
  - Dotplots of Y vs. Discrete X
  - Scatterplots or Matrix plots of Y vs. Continuous X
  - Main Effects Plot of Y vs. Discrete X
- Use statistical techniques to validate the graphical results:
  - T-test on Discrete X
  - ANOVA on Discrete X
  - Regression on Continuous X

Data	Description	Hypothesis	Graphical Tool	Test
	A | B | C R | 5 | 10 | 25 S | 80 | 50 | 75	Discrete X Discrete Y	H_0: Factors are independent	Not Applicable	Chi-Square
	Continuous Y compared to target/goal	H_0: μ = Target	Box plot, Dot Plot	1-Sample t
	2 levels of Discrete X, Continuous Y	H_0: $\mu_1 = \mu_2$	Box plot, Dot plot, Main Effects	2-Sample t
	3+ levels of Discrete X, Continuous Y	H_0: $\mu_1 = \ldots = \mu_k$	Box plot, Dot plot, Main Effects	ANOVA
	Continuous X; Continuous Y	H_0: Slope = 0	Scatter plot, Matrix plot	Regression

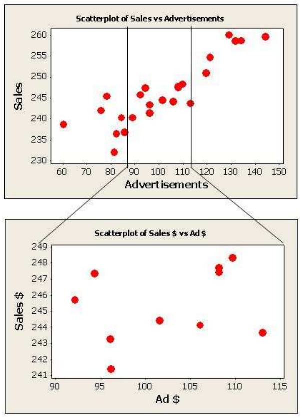


Output Y Type	Input X Type	Levels of X	Number of Xs	Comparison of ...	Statistical Test	Minitab
Discrete	Discrete	≥2	1	Frequency	Chi-Square	Stat > Tables > Chi-Square Test
Continuous	Discrete	1	1	Mean	1-Sample t-Test	Stat > Basic Statistics > 1-Sample t
				Median	1-sample Wilcoxon	Stat > Nonparametrics > 1-Sample Wilcoxon
		2	1	Means	2-Sample t-Test	Stat > Basic Statistics > 2-Sample t
				Mediums	Mann-Whitney	Stat > Nonparametrics > Mann-Whitney
				Means	Paired t-Test	Stat > Basic Statistics > Paired t
		≥2	1	Means	ANOVA	Stat > ANOVA > One-Way
				Mediums	Kruskal-Wallis	Stat > NonParametrics > Kruskal-Wallis
			≥2	Means	GLM	Stat > ANOVA > General Linear Model
	Continuous	Many	1	-NA-	Regression	Stat > Regression > Fitted Line Plot
						Stat > Regression > Regression
			≥2	-NA-	Regression	Stat > Regression > Stepwise
						Stat > Regression > Best Subsets

Multi-Vari Tips

- Include the following when presenting the Multi-Vari results:
    - Objectives: Inputs and outputs studied, theories and hypotheses
    - Stability: Control charts to track key x's; project y(s)
    - Significant results: Using BOTH graphs and statistical analysis, demonstrate the practical and statistical significance of inputs on outputs. Often helpful to also show which inputs were proved insignificant.
    - Conclusions: Recommendations for next steps (ie: further data collection & studies, experiments, etc)
- During planning of the Multi-Vari study, consult with a Black Belt or a Green Belt Coach for other potential considerations.
- Refer to the Roadmaps for graphs and statistical tools while planning & analyzing your data.
- Some people like to do a Multi-Vari study before the FMEA to learn more about the process and to identify other X's.
- Organize your questions and data analysis plans before collecting any data (use the Multi-Vari Study Worksheet).
- Look at everything that seems pertinent.
- See the Multi-Vari planning worksheet in Appendix and tool in Ubertool.

Common Multi-Vari Analysis Pitfalls



- Passive observation can provide too narrow of a range of “X” behavior – especially for controlled variables (see chart on right).
- Interactions may be present, but we have only investigated one input (X) at a time.
- Multicollinearity (Confounding) may be present. Occurs when the Xs are correlated with each other. Makes it difficult to determine which X has a real effect.
- Biases (conscious or unconscious) limit the way we look at data or situations. Be aware of them and include a variety of people and thoughts in the planning, collecting and analyzing of the data.
- Recall the “Laws of Snapshooting”: What you look at is what you see and what you look for is what you find.

Reporting Multi-Vari Results

- Include in final report:
    - Description of what trying to accomplish (plan): objectives, input and output variables measured, sampling plan used to collect data, and process settings
    - Stability of process: trend/control charts, histograms
    - Results for each X (significant relationships): graphical analysis (e.g. boxplots, scatterplots) and statistical analysis
    - Conclusions of findings: recommendations for further studies, areas to focus improve efforts
- Conclusions should be:
    - Supported by data (not based on conjecture or intuition)
    - Shown in graphical and statistical format
    - Sensible from a process standpoint

Multi-Vari Checklist

☐ Who helped developed the Multi-Vari analysis study?
☐ How was the study conducted?
☐ Were all parts of the process adequately represented in the study (plan, results for each X, summary)?
☐ What were the results? And, what do they tell us needs to be done going forward?

Next Steps

- Revisit FMEA and develop recommended actions for key inputs (X’s).
- Develop improvement strategy (e.g. designed experiment, pilot, simulation) to test out your potential solutions.

Lessons Learned

B. Survey/Questionnaire Tip Sheet

Why use surveys/questionnaires?

- Cost effective
- Large samples in short time frame
- Easy to tabulate
- No interviewer bias
- Convenient to fill out
- Uniform presentation of questions

Administering Surveys/Questionnaires Modes: Mail, Fax, Email, Phone, Internet

Upfront Survey Planning:

- What is the main question or objective(s)?
- What's the timeline?
- Who is target audience? How will they be selected?
- What are the Ys and Xs to be collected?
- How will survey be administered?
- How will data be analyzed?

Plan ahead for:

- Turnaround time
- Approximate costs
- Incentives
- Formats and number of questions
- Number of reminders to increase response rate
- Sample size for the costs
- Time before last survey

Constructing the Questions:

- Single most difficult task, but **most critical!**
- Clarity of meaning of each question very important
- Always PRE-TEST the questionnaire
- Use different formats depending on information needed (depends on X and Y)
  - Free-answer (open-ended)
  - Dichotomous – Only 2 possible responses
  - Multiple-choice – choosing one from many options – nominal, ordinal, or "scale" rating
  - Fill-in-the blanks (number or word)
  - Ranking based on specified criterion

Asking the questions – DO's:

- Use language familiar to the audience
- Be clear as to wanting fact or opinion as response
- Ask people about their firsthand experiences and where they can give informed answers
- Questions should be worded so that all respondents are answering the same question
- All respondents should have the same sense of is what the meaning; provide definitions where necessary
- Write good operational definitions for all rating levels
- If definitions are to be given, give them before the question itself is asked.
- Limit questions to relate only to suspected critical Xs
- Limit open-ended questions – they are insightful but can be difficult to directly relate Xs to Ys
- Do a pilot study for your survey – not just to your friends, but to potential recipients
- Plan data analysis before launching full survey
- If what is to be covered is too complex to be included in a single question, ask multiple questions.

Asking the questions – AVOID:

- Phrasing questions in a manner that suggests a response (*"Do you think your hard-working senator's proposal is a good one?")*
- Adverbs/adjectives that convey different meanings to different people (Several, many, most, usually…)
- Words with double meanings
- Words that evoke emotional overtones
- Double negatives
- "If yes, then…" questions
- Asking information that is only acquired second hand
- Asking for solutions to complex problems
- Asking questions that have two questions included (*"Do you fall asleep quickly and sleep soundly?")*

Survey Responses:

- Should be a category for every possible answer
- Include a “don’t know” category if respondents might not be able to answer
- Categories should be mutually exclusive and independent
- Provide a continuum to evaluate and respond
- Define what is to be rated
- Use an Agree-Disagree format for relativity in subjective questions attitudes, opinions and assessments
- Narrative Answers (Open-ended) when cannot categorize
- If respondents are filling in blanks, make it clear what is to be put there
- For sensitive, personal, or difficult-to-capture issues, consider using categories rather than filling in blanks. For example: salary, age, weight, etc; percent of time spent online.

Scales/Number of Categories:

Amount:	“Too little” to “Too much” (often 5); Best answer may be “Just-about right”
Intensity (strength of characteristic)	None” to “Very strong” (often 5 or 7)
Frequency	“Never” to “Very often” or “Always” (from 3, 5 or 7)
Agreement	“Extremely disagree” to “Extremely agree”, with middle of “Neither agree or disagree” (often 7 or 9 or 10)
Liking	“Extremely dislike” to “Extremely like” (5 or 9 or 10, depending on the descriptors)

Data Collection:

- Choose how you plan to conduct the survey
- Pilot test it!
- Check for errors, complaints, verify data structures, accuracy, delivery then launch
- Determine how to increase response rates to survey
- Send reminders
- Monitor response rates

Choosing a Sample:

- Identify the number of people needed
- Identify the right people – people with information on Xs
- A representative sample ensures validity without extreme amounts of data

Common Pitfalls:

- Bad measurement system for Y. Using surveys to obtain Y data can be extremely suspect – typically MSA issues with data reliability. If Y is discrete (pass or fail), need a LOT of data and a statistician’s help. Bad Y means a bad Multi-Vari Study.
- Too many open-ended questions – they don’t link Xs directly to Y.
- Too many questions – remember: suspected critical Xs, not every X.

Key Final Points:

- Keep total length to a minimum
- Focus questions on learning areas and objectives defined upfront
- Pre-Test and Pilot the survey—A Must!
- May need follow-up reminders
- Avoid “it would be nice to know” questions!
- Use cover letters with instructions, timing, anonymity issues
- Wording is key

C. Hypothesis Testing

Steps to Test an Hypothesis

An hypothesis is simply a theory that is proved/disproved using data. Hypothesis testing allows us to properly handle uncertainty, minimize subjectivity, question assumptions, prevent omission of critical information, and manage the risk of decision errors.

Step 1 – Determine the Null Hypothesis

- Presume there is **no difference** between the options (e.g. supplier A versus supplier B). This is called the ***Null Hypothesis*** (***H_o***).
- Assume the Null Hypothesis (H_o) is true. Frequently the Null Hypothesis (H_o) is the opposite of what we hope to show.
- Easier to disprove than to prove.
- Hypothesis definitions:
    - H_0: Null hypothesis
    - H_a: Alternative hypothesis

Step 2 – Collect data (e.g. using Multi-Vari Studies) and calculate test statistic (signal to noise ratio)

Step 3 – Check to see if data provide evidence there is a statistical difference

- Using a statistical tool, calculate the p-value (α).
    - **p-value** = Probability value: Probability the observed results could occur if H_o is true.
        - Low p-value, then low probability H_o is true. Reject the H_o. **“P is low, H_o must go!”**
        - High p-value, then high probability H_o is true. Accept the H_o. **“P is high, H_o’s the guy!”**
        - p-value based on assumed or actual distribution (Normal, t-distribution, Chi-Square, F-distribution, etc.)
        - For most cases if the p-value (α) < 0.05, there is a statistical difference.

p-Value	Interpretation	Reaction
p-value > 0.10	No significance	Keep the null hypothesis
0.10 > p-value > 0.05	Weak significance	Potentially reject null hypothesis (H_o) – keep studying the variable
0.05 > p-value > 0	Strong significance	Reject null hypothesis (H_o)

- If there **is** a statistical difference, then **reject** the Null Hypothesis (H_o) – there **is a difference** between the options.
- If there **is not** a statistical difference, then **accept** the Null Hypothesis (H_o) – there is **no difference** between the options.
- Basically, innocent until proven guilty.

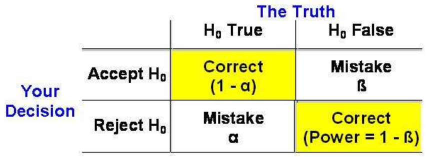
Step 4 – Check to see if there is a practical difference

- Practical significance addresses the question “do I care?”
- p-Values indicate statistical significance. However, also need to assess **practical** significance by looking at the size of the difference between the two groups. **Note**: Remember statistical significance is affected by sample size, so statistical and practical significance do not necessarily go together.
    - Are differences large enough to matter? If so, they are practically significant.
    - Factors that are **both** statistically and practically significant can be used to manipulate the process.

		Statistical Significance	
		Yes	No
Practical Significance	Yes	Act on it	Get more data
	No	Ignore it for now	Drop it

Decision Errors

- When testing a hypothesis, we do so with a known degree of risk and confidence.
- There are two kinds of decision risk in hypothesis testing:
    - Rejection of null hypothesis (H_o) when it is true (α, Type I error).
    - Acceptance of null hypothesis (H_o) when it is false (β, Type II error)

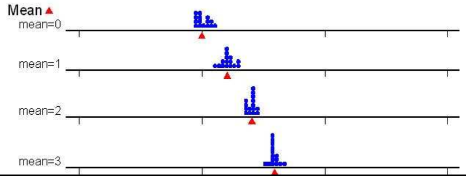
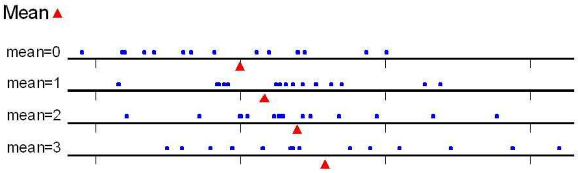


		The Truth	
		H_0 True	H_0 False
Your Decision	Accept H_0	Correct (1 - α)	Mistake ß
	Reject H_0	Mistake α	Correct (Power = 1 - ß)

- To determine appropriate sample size, we must specify in advance: magnitude of acceptable decision risk and test sensitivity. Consider practical limitations of cost, time, and available resources to arrive at a rational sampling plan.

Signal to Noise

- **Signal** is the change or difference we are trying to detect. Difference between process average and target (bias).
- **Noise** is the inherent variability in the system. Based on process variation.
- If the ratio is:
    - **Small** – there is no real signal or difference – it's just noise. Results will be displayed as a large p-value.
    - **Large** – the signal or difference is seen over and above the noise – it's "real". Results will be displayed as a small p-value.
    - If the signal-to-noise ratio is large enough, we conclude that the effect is real

• Larger signals are easier to detect • Smaller noise makes it easier to detect signals	
• Smaller signals are harder to detect • Larger noise makes it harder to detect signals	

Hypothesis Testing versus Confidence Intervals

Confidence intervals are a concept related to hypothesis testing:

- **Hypothesis tests** tell whether or not there is a statistical difference.
- **Confidence intervals** give you an estimate of what the difference is (if any). They take into account variability of process. They provide more information about uncertainty of conclusions. They are similar in concept to control limits on a control chart. They will generally be a part of Minitab output along with p-value.

Sample Size Cookbook

See your Black Belt or Coach for assistance with determining sample size. If you'd like to try on your own, here is the "Sample Size Cookbook."

1. Define problem
2. Develop objectives
3. Establish hypotheses
4. Design test
    a) Establish Alpha (α)
        - Choice of α should depend upon practical considerations – financial risk, safety risk, or other risk to the customer
        - Typical value is $\alpha = 0.05$
        - What are the consequences of rejecting H_0?

    b) Establish Beta (β)
        - Typical values are $\beta = 0.10$ or 0.20
        - The power of a test is equal to $1-\beta$
            - High power (e.g., 0.8 or larger) improves the chance of successfully identifying improvement opportunities
        - This risk is especially important when trying to show that an X has no effect.
        - If the averages differ by δ, what are the consequences of failing to detect it?

    c) Establish Delta (δ)
        - The minimum difference (δ) from the hypothesized value we want to detect with power $1-\beta$
        - δ is the "Signal" we're trying to detect in the Signal/Noise ratio
        - How far apart should the averages be for practical significance?

    d) Establish Sigma (σ)
        - If there's no good estimate of σ, we can work with the ratio δ/σ to specify the effect in relative terms (e.g., we may be looking for a 2σ effect)

    e) Establish Sample Size (n)
        - For tests of the mean, the relationship among the five variables α, β, δ, σ, and n determine the sample size
        - If we know any four of the five variables, we can calculate the fifth
5. Devise sampling plan
6. Conduct test
7. Measure and record data
8. Conduct statistical test
9. Make statistical decision
10. Translate decision into action

** The guidelines for sample sizes are (more data means higher confidence):

- Comparing **Mean** = 5-10 for each group
- Comparing **Standard Deviation** = 25-30 for each group
- Analyzing **Survey** = 50 for each category of study

Minitab Example

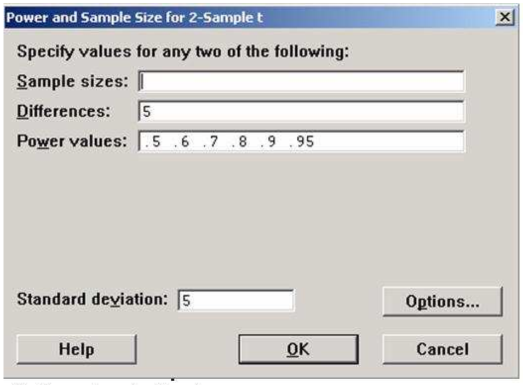
Minitab has sample size calculation tools that can be used to determine the appropriate sample sizes. The following Minitab examples are for continuous data.

- **Question:** How much data do I need to detect a difference of 5 units between two populations when each population has a standard deviation of 5 units?

  In Minitab: *Stat > Power and Sample Size > 2-Sample t-Test >*
  Sample Sizes: leave blank,
  Differences: Enter the difference between the population means you are trying to detect (e.g. 5),
  Power Values: Enter the desired probability of being able to detect the specified difference (e.g. .5 for 50%, .95 for 95%),
  Standard Deviation: Enter the estimate of the population standard deviation (e.g. 5)

  > Options: Significance level: Default is alpha (α) of .05.

  Results: See Minitab table at right that displays the Sample Size for each target Power Value. For this example, sample size of 27 to be 95% confident of detecting a difference of 5 units when the standard deviation is 5 units. Only 17 samples (data points) needed to be 80% confident in the shift.



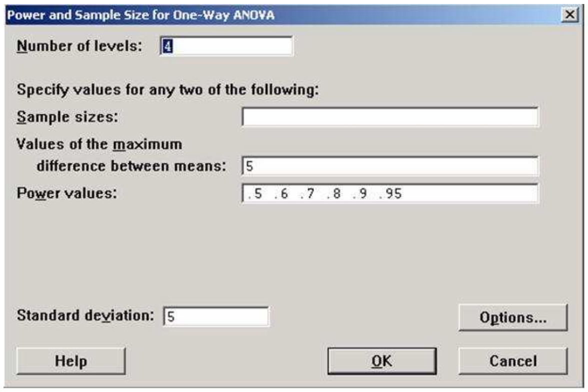
Specify values for any two of the following:
Sample sizes:
Differences: 5
Power values: .5 .6 .7 .8 .9 .95
Standard deviation: 5

```
2-Sample t Test
Testing mean 1 = mean 2 (versus not =)
Calculating power for mean 1 = mean 2 + difference
Alpha = 0.05  Assumed standard deviation = 5
            Sample  Target
Difference    Size   Power  Actual Power
         5       9    0.50      0.513363
         5      11    0.60      0.607098
         5      14    0.70      0.721420
         5      17    0.80      0.807037 ←
         5      23    0.90      0.912498
         5      27    0.95      0.950077 ←
The sample size is for each group.
```

- **Question:** How much data do I need to detect a difference of 5 units between three or more populations (levels) when each has a standard deviation of 5 units?

  In Minitab: *Stat > Power and Sample Size > One-Way ANOVA >*
  Number of levels: Enter the number of levels (e.g. 4)
  Sample Sizes: leave blank,
  Values of the maximum difference between means: Enter the difference between the largest and smallest level means you are trying to detect (e.g. 5),
  Power Values: Enter the desired probability of being able to detect the specified difference (e.g. .5 for 50%, .95 for 95%),
  Standard Deviation: Enter the estimate of the population standard deviation (e.g. 5)
  > Options: Significance level: Default is alpha (α) of .05.

  Results: See Minitab table at right that displays the Sample Size for each target Power Value. Sample size of 36 to be 95% confident of detecting a difference of 5 units when the standard deviation is 5 units. Only 23 samples (data points) needed to be 80% confident in the shift.



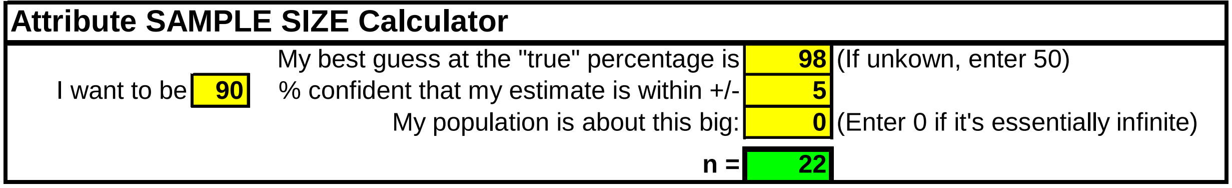
Number of levels: 4
Specify values for any two of the following:
Sample sizes:
Values of the maximum difference between means: 5
Power values: .5 .6 .7 .8 .9 .95
Standard deviation: 5

```
One-way ANOVA
Alpha = 0.05  Assumed standard deviation = 5
Number of Levels = 4
          Sample  Target                    Maximum
SS Means    Size   Power  Actual Power   Difference
    12.5      13    0.50      0.517637            5
    12.5      16    0.60      0.622529            5
    12.5      19    0.70      0.711148            5
    12.5      23    0.80      0.803863            5 ←
    12.5      30    0.90      0.907115            5
    12.5      36    0.95      0.953837            5 ←
The sample size is for each level.
```

Excel Examples

"Sample Size Calculator.xls" is commonly used for determining audit sample size. It is found in the Information & Tools Database.

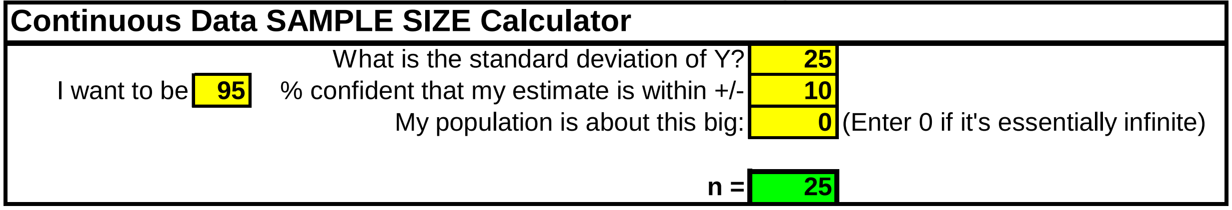
- **Attribute Audit** – Assume an infinite population and I suspect that the database is 98% accurate (match). I want to be 90% sure that this is true within 5% (or I'm 90% confident I'm between 93% to 103% accurate).



Attribute SAMPLE SIZE Calculator

My best guess at the "true" percentage is 98 (If unkown, enter 50)
I want to be 90 % confident that my estimate is within +/- 5
My population is about this big: 0 (Enter 0 if it's essentially infinite)
n = 22

- **Continuous Sample** – I want to detect a shift of 10 units in a continuous Y when the standard deviation is 25 units. I want to be 95% sure there has been a change in Y.



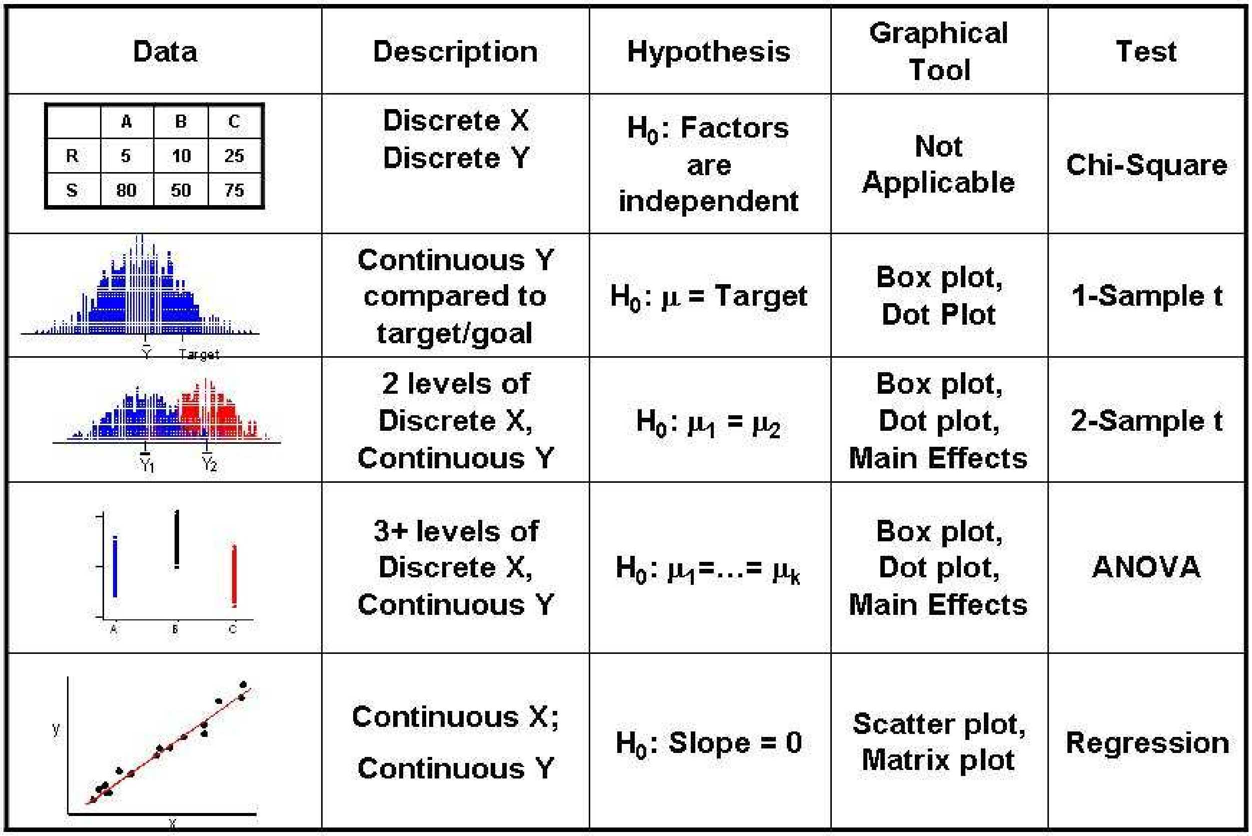
Continuous Data SAMPLE SIZE Calculator

What is the standard deviation of Y? 25
I want to be 95 % confident that my estimate is within +/- 10
My population is about this big: 0 (Enter 0 if it's essentially infinite)
n = 25

D. Statistical Tests

Which Statistical Test Do I Use?

The following statistical roadmap provides a structured approach to statistical tools. The tool to be used is dependent on the type of data (continuous versus discrete).



Data	Description	Hypothesis	Graphical Tool	Test
A B C R 5 10 25 S 80 50 75	Discrete X Discrete Y	H_0: Factors are independent	Not Applicable	Chi-Square
	Continuous Y compared to target/goal	H_0: μ = Target	Box plot, Dot Plot	1-Sample t
	2 levels of Discrete X, Continuous Y	H_0: $\mu_1 = \mu_2$	Box plot, Dot plot, Main Effects	2-Sample t
	3+ levels of Discrete X, Continuous Y	H_0: $\mu_1 = \ldots = \mu_k$	Box plot, Dot plot, Main Effects	ANOVA
	Continuous X; Continuous Y	H_0: Slope = 0	Scatter plot, Matrix plot	Regression

How Do I Stack My Data?

Hint: It's easier to get useful graphs and analyses when data are in same column (e.g. single column for Y, one column for each X).

In Minitab: To stack data in Minitab:
Data > Stack > Columns > Stack the following columns: Select the columns you want to stack; Column of current worksheet: Enter the name for the output (Y) column; Store subscripts in: Enter the name for the input (X) column; Check the "Use variable names in subscript column" box
Results: Data will be stacked in one column for X and one column for Y.

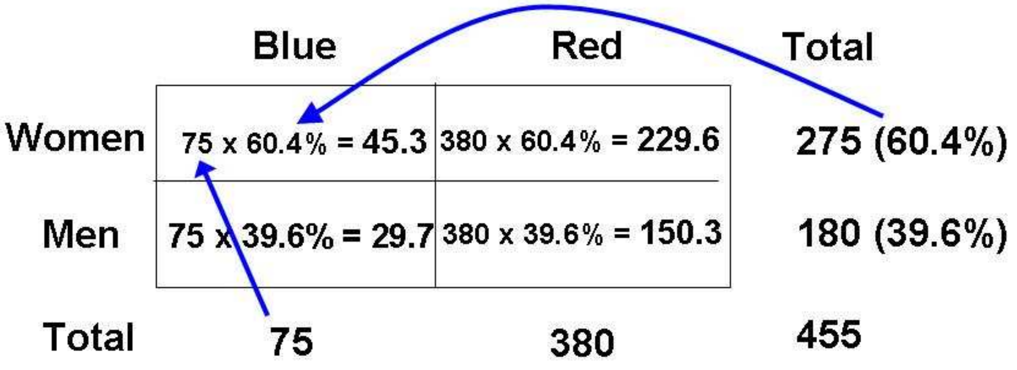
Chi-Square

Chi-Square is a test to see if a discrete input (X) and discrete output (Y) are independent.

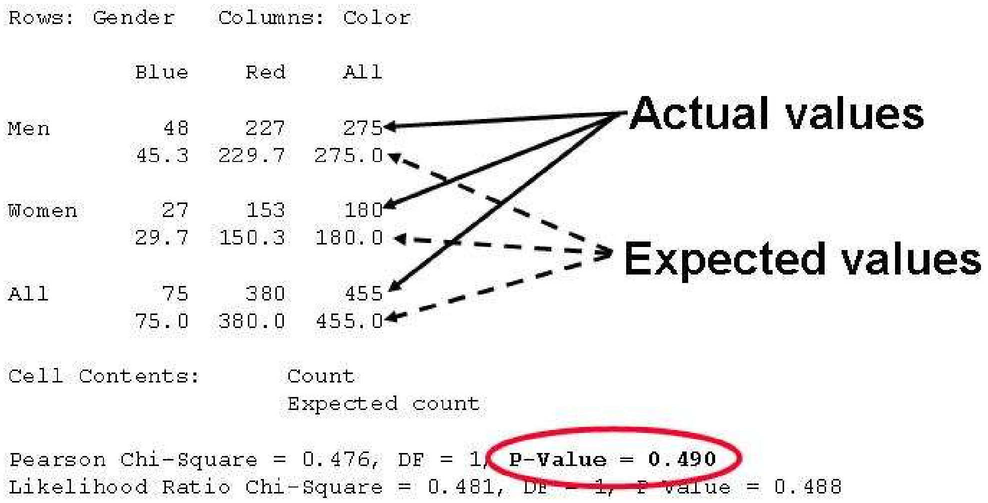
- H_o presumes they are independent
  - H_0: Data are *Independent* (e.g. Color preference *is not* influenced by gender)
  - H_a: Data are *Dependent* (e.g. Color preference *is* influenced by gender)
  - **Example:** If gender and color preference are independent, percent of women who prefer blue should be approximately same as percent of men who prefer blue.
- Chi-Square test determines statistical significance. Chi-Square statistic is based on expected and observed frequencies (and the number of categories for X and Y). For example:
  - Count *observed* number of:
    - Women who prefer blue and women who prefer red
    - Men who prefer blue and men who prefer red
  - Determine number that would be *expected* if gender and color preference were independent.
  - Use Minitab's Chi-Square test to calculate expected number and p-value. If p-value is < 0.05, reject $H_{0.}$

$$\chi^2 = \sum \frac{(\text{Observed- Expected})^2}{\text{Expected}}$$

- Expected frequencies for each group must be at least five for the Chi-Square to meet assumptions
- ***In Minitab:*** To calculate Chi-Square in Minitab:
  Stat > Tables > Cross Tabulation and Chi-Square; Rows is "Discrete X"; Columns is "Discrete Y"; Frequencies is "actual" values; Display: Check the "Counts" box; Chi-Square…: Check the "Chi-Square analysis" and "Expected Cell Counts" boxes
  Results: Look for p-value to see if should reject null hypothesis.



	Blue	Red	Total
Women	75 x 60.4% = 45.3	380 x 60.4% = 229.6	275 (60.4%)
Men	75 x 39.6% = 29.7	380 x 39.6% = 150.3	180 (39.6%)
Total	75	380	455

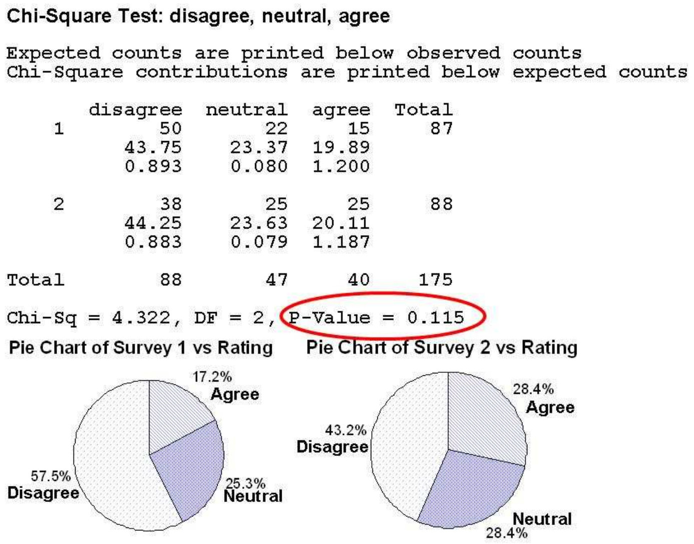


```
Rows: Gender   Columns: Color

          Blue    Red    All

Men         48    227    275
          45.3  229.7  275.0

Women       27    153    180
          29.7  150.3  180.0

All         75    380    455
          75.0  380.0  455.0

Cell Contents:      Count
                    Expected count

Pearson Chi-Square = 0.476, DF = 1, P-Value = 0.490
Likelihood Ratio Chi-Square = 0.481, DF = 1, P-Value = 0.488
```

Example:

- **Question:** Did my project shift the survey results to a more positive outcome?

  Results: No significant change in results of survey (satisfaction) between survey 1 and 2 (P-Value = 0.115).

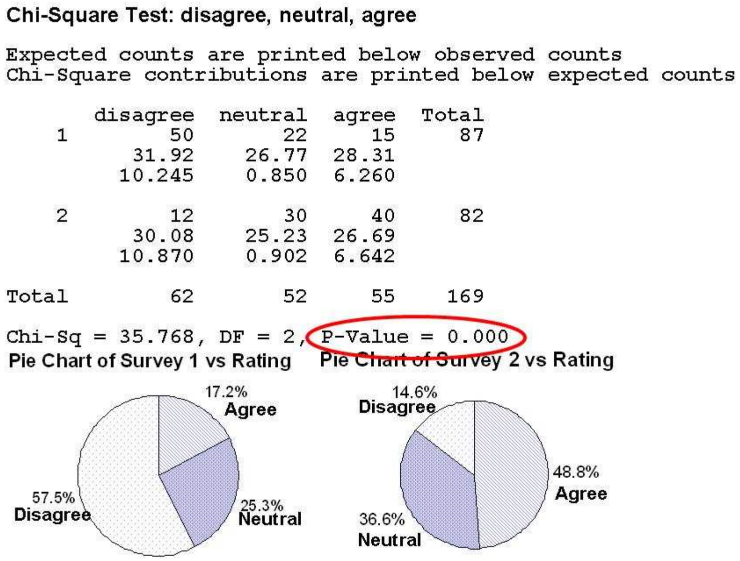


Chi-Square Test: disagree, neutral, agree

```
Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

       disagree  neutral  agree  Total
    1        50       22     15     87
          43.75    23.37  19.89
          0.893    0.080  1.200

    2        38       25     25     88
          44.25    23.63  20.11
          0.883    0.079  1.187

Total        88       47     40    175

Chi-Sq = 4.322, DF = 2, P-Value = 0.115
```

- **Same Question Different Data and Different Result:** Did my project shift the survey results to a more positive outcome?

  Results: Significant change in results of survey (satisfaction) between survey 1 and 2 (P-Value = 0.000).



Chi-Square Test: disagree, neutral, agree

```
Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

       disagree  neutral  agree  Total
    1        50       22     15     87
          31.92    26.77  28.31
         10.245    0.850  6.260

    2        12       30     40     82
          30.08    25.23  26.69
         10.870    0.902  6.642

Total        62       52     55    169

Chi-Sq = 35.768, DF = 2, P-Value = 0.000
```

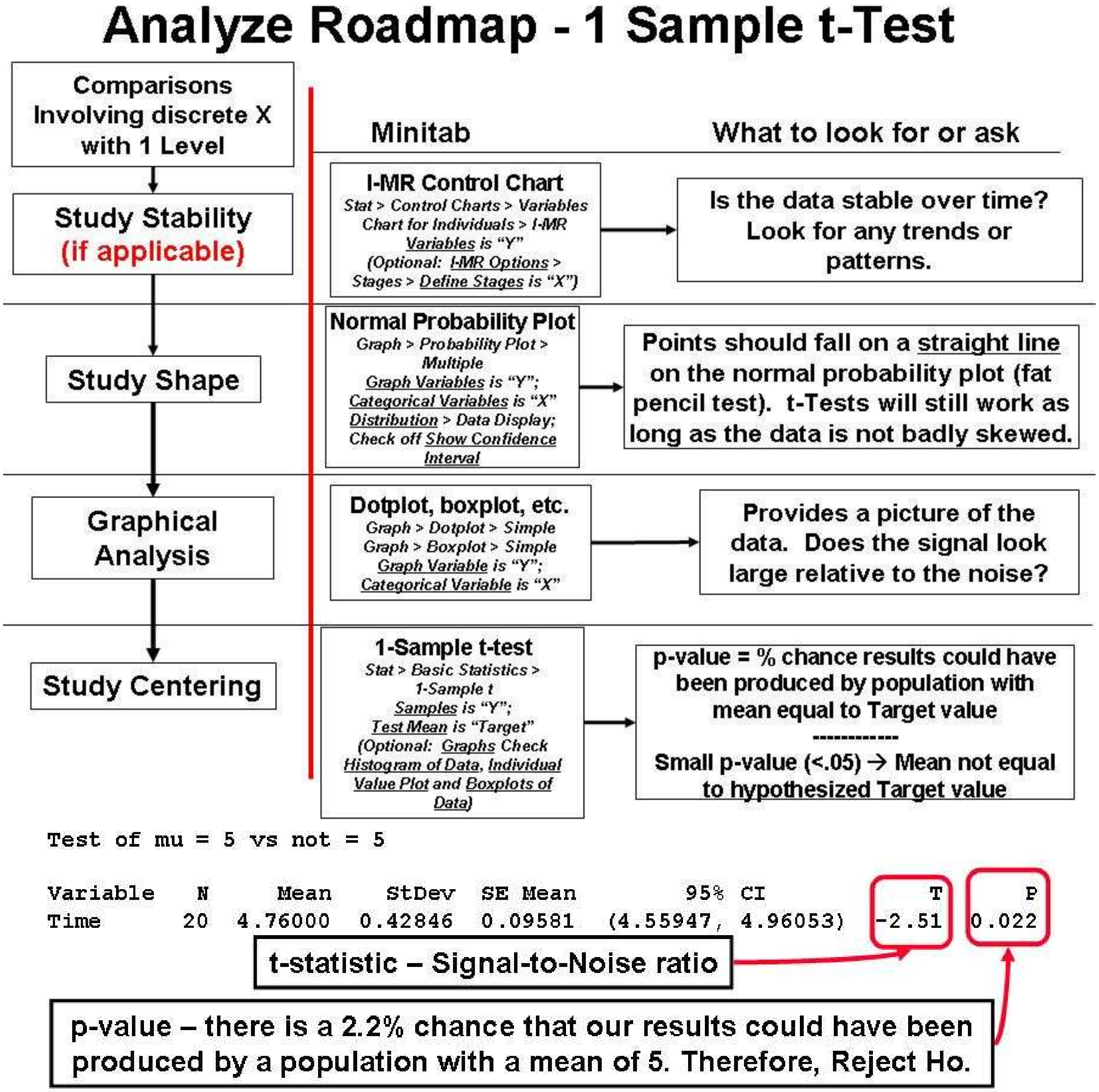
Chi-Square Comments:

- Can be useful for discrete Y and for highly skewed continuous Y.
- At least 80% of expected frequencies must be > 5 for Chi-Square Test to meet assumptions.
  - If expected frequencies are less than 1, Minitab will not calculate a p-value.
  - Categories can be combined to overcome this issue.
- Data should be gathered to assure randomness – beware of other hidden factors (Xs).

1-sample t-Test

1-sample t-Test is used to compare a continuous output (Y) average (μ) and a specific value (e.g. target, goal, belief).

- The test is a Signal-to-Noise ratio that compares sample averages to what would be expected if H_0 were true.
    - Signal is the difference between the average and target (μ – Target).
    - Noise is the standard deviation of the differences.
- Data should be stable and normal. Test still performs well with moderate departures from normality
- See the following roadmap for how to conduct a 1-sample t-Test.



Analyze Roadmap - 1 Sample t-Test

Comparisons Involving discrete X with 1 Level

Minitab

What to look for or ask

Study Stability (if applicable)

I-MR Control Chart
Stat > Control Charts > Variables Chart for Individuals > I-MR
Variables is "Y"
(Optional: I-MR Options > Stages > Define Stages is "X")

Is the data stable over time? Look for any trends or patterns.

Study Shape

Normal Probability Plot
Graph > Probability Plot > Multiple
Graph Variables is "Y"; Categorical Variables is "X"
Distribution > Data Display; Check off Show Confidence Interval

Points should fall on a straight line on the normal probability plot (fat pencil test). t-Tests will still work as long as the data is not badly skewed.

Graphical Analysis

Dotplot, boxplot, etc.
Graph > Dotplot > Simple
Graph > Boxplot > Simple
Graph Variable is "Y"; Categorical Variable is "X"

Provides a picture of the data. Does the signal look large relative to the noise?

Study Centering

1-Sample t-test
Stat > Basic Statistics > 1-Sample t
Samples is "Y"; Test Mean is "Target"
(Optional: Graphs Check Histogram of Data, Individual Value Plot and Boxplots of Data)

p-value = % chance results could have been produced by population with mean equal to Target value

----

Small p-value (<.05) → Mean not equal to hypothesized Target value

```
Test of mu = 5 vs not = 5

Variable   N     Mean    StDev  SE Mean         95% CI               T      P
Time      20  4.76000  0.42846  0.09581  (4.55947, 4.96053)  -2.51  0.022
```

t-statistic – Signal-to-Noise ratio

p-value – there is a 2.2% chance that our results could have been produced by a population with a mean of 5. Therefore, Reject Ho.

2-sample t-Test

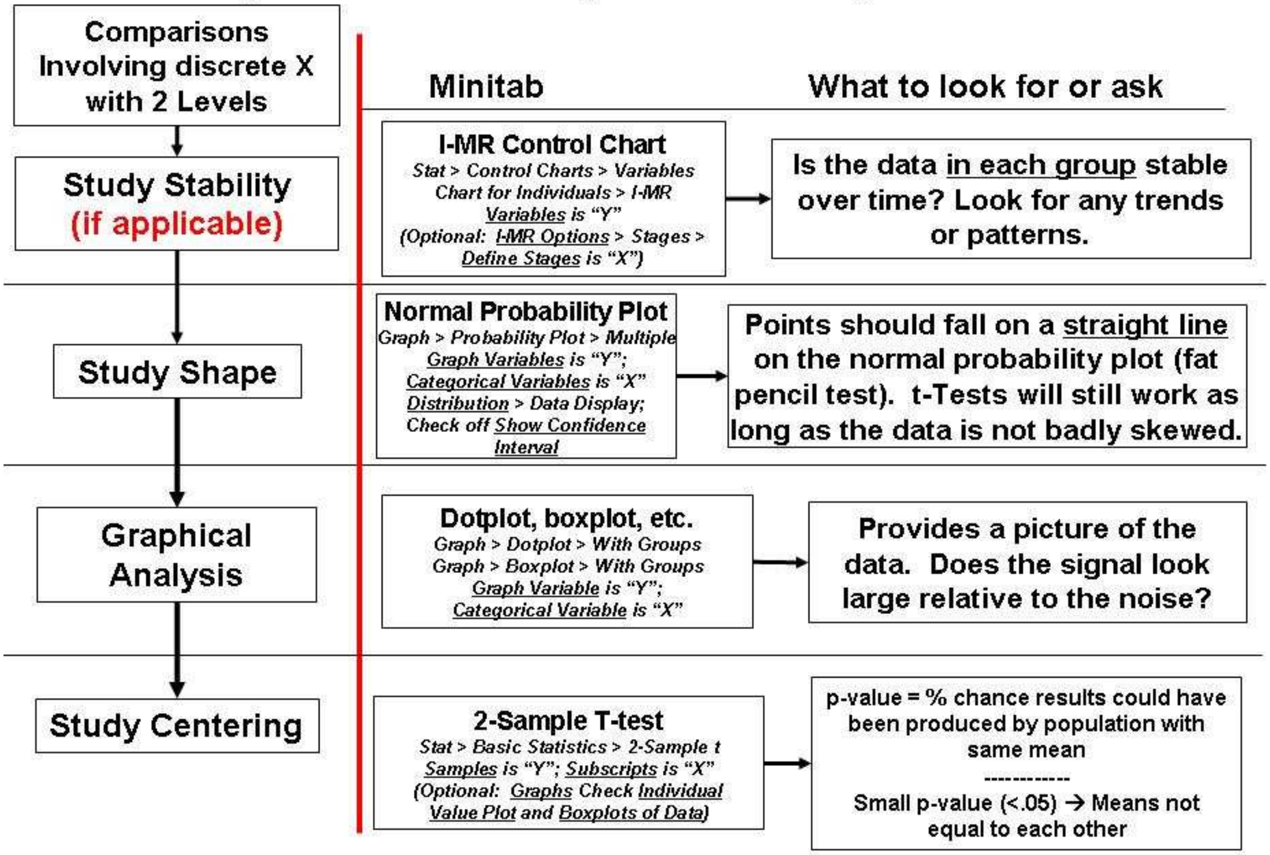
2-sample t-Test is used to compare a discrete input (X) with two levels (e.g. Supplier A and Supplier B) and a continuous output (Y). 2-sample t-Test answers the question: is the mean of Supplier A different than the mean of Supplier B?

- The test is a Signal-to-Noise ratio that compares the two sample averages to each other.
    - Signal is the difference between the two averages ($\mu_a - \mu_b$).
    - Noise is the standard deviation of the differences.

$$\text{Signal} = \bar{X}_1 - \bar{X}_2 \qquad \text{Noise} = \sigma_{\bar{X}_1 - \bar{X}_2} = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$$

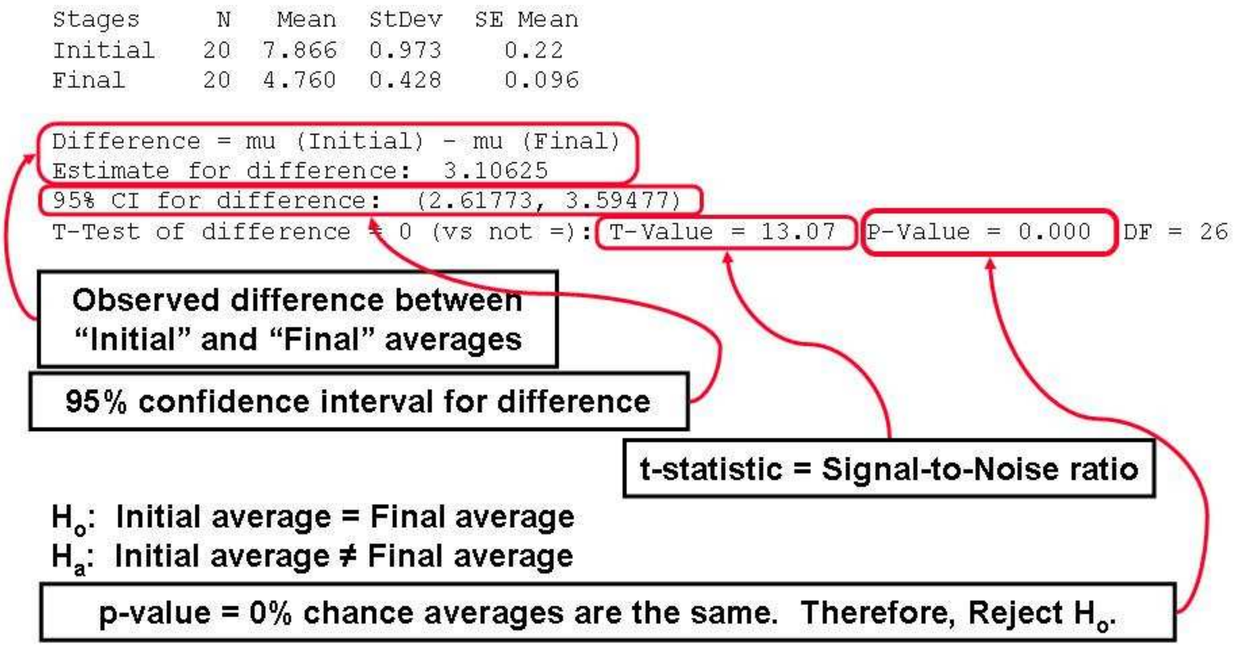
- t-Test makes two assumptions: data are stable and normal. t-Test still performs well with moderate departures from normality**.**
- Sample size **does not** have to be equal.
- **Example:** Common use of the 2-sample t-Test is with initial and final (or improved) capability. Question being asked is – did my project produce a shift in the performance of the process? H_o: Initial capability = Final capability
- See the following roadmap for how to analyze a 2-sample t-Test.

Analyze Roadmap – 2 Sample t-Test



Comparisons Involving discrete X with 2 Levels

	Minitab	What to look for or ask
Study Stability (if applicable)	**I-MR Control Chart** *Stat > Control Charts > Variables Chart for Individuals > I-MR* *Variables is "Y"* *(Optional: I-MR Options > Stages > Define Stages is "X")*	Is the data in each group stable over time? Look for any trends or patterns.
Study Shape	**Normal Probability Plot** *Graph > Probability Plot > Multiple* *Graph Variables is "Y";* *Categorical Variables is "X"* *Distribution > Data Display;* *Check off Show Confidence Interval*	Points should fall on a straight line on the normal probability plot (fat pencil test). t-Tests will still work as long as the data is not badly skewed.
Graphical Analysis	**Dotplot, boxplot, etc.** *Graph > Dotplot > With Groups* *Graph > Boxplot > With Groups* *Graph Variable is "Y";* *Categorical Variable is "X"*	Provides a picture of the data. Does the signal look large relative to the noise?
Study Centering	**2-Sample T-test** *Stat > Basic Statistics > 2-Sample t* *Samples is "Y"; Subscripts is "X"* *(Optional: Graphs Check Individual Value Plot and Boxplots of Data)*	p-value = % chance results could have been produced by population with same mean ------------ Small p-value (<.05) → Means not equal to each other



```
Stages      N   Mean  StDev  SE Mean
Initial    20  7.866  0.973     0.22
Final      20  4.760  0.428    0.096

Difference = mu (Initial) - mu (Final)
Estimate for difference:  3.10625
95% CI for difference:  (2.61773, 3.59477)
T-Test of difference = 0 (vs not =): T-Value = 13.07  P-Value = 0.000  DF = 26
```

Observed difference between "Initial" and "Final" averages

95% confidence interval for difference

t-statistic = Signal-to-Noise ratio

H_o: Initial average = Final average

H_a: Initial average ≠ Final average

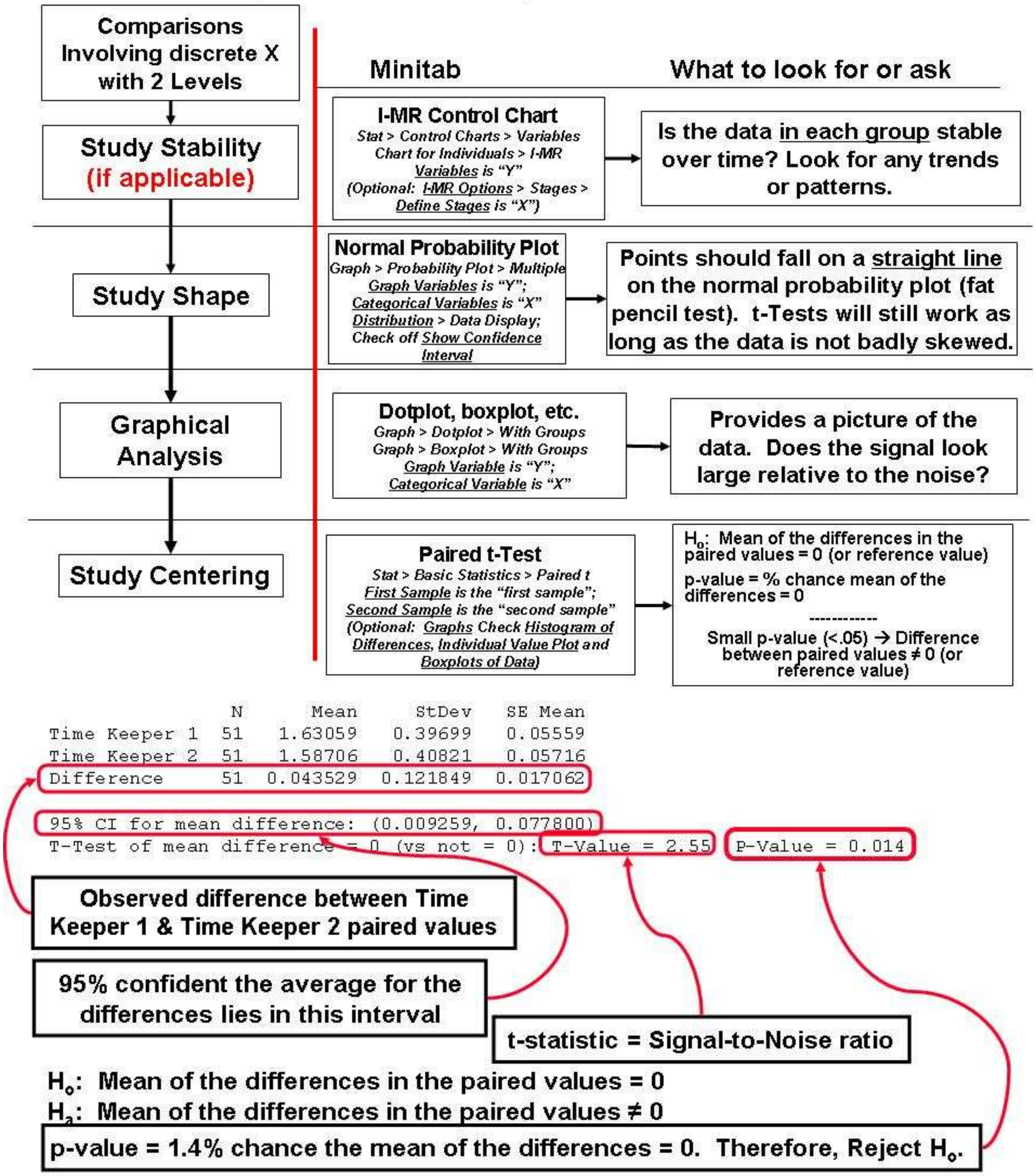
p-value = 0% chance averages are the same. Therefore, Reject H_o.

Paired t-Test

Paired t-Test is used when comparing two paired continuous (Y) measurements of the same process or event. The data must be related in some way.

- The test is a Signal-to-Noise ratio that compares the population mean of the differences to the hypothesized mean of the differences (often H_o is mean of difference = 0, not always).
    - Signal is the difference between the two ($\mu_d = \mu_0$).
    - Noise is the standard deviation of the differences.
- The number of data points must be the same for each group and organized in pairs with the same relationship. This test looks at differences between the matched pairs and is therefore able to factor out noise that happens among the pairs.
- Examples: a) Two observers collect inventory data on the same day. Are they the same? b) Two testers each collect the same time to process the same part during a manufacturing run. Do their results match? c) Two people watch the same paper helicopter drop. Do their flight times match? d) One patient is evaluated before and after a new drug treatment. Is there a difference in the patient's condition?
- Test assumes the paired differences are independent and identically normally distributed. Test still performs well with moderate departures from normality.
- See the following roadmap for how to analyze a Paired t-Test.

Analyze Roadmap – Paired t-Test



Comparisons Involving discrete X with 2 Levels

Minitab

What to look for or ask

Study Stability (if applicable)

I-MR Control Chart
Stat > Control Charts > Variables Chart for Individuals > I-MR
Variables is "Y"
(Optional: I-MR Options > Stages > Define Stages is "X")

Is the data in each group stable over time? Look for any trends or patterns.

Study Shape

Normal Probability Plot
Graph > Probability Plot > Multiple
Graph Variables is "Y";
Categorical Variables is "X"
Distribution > Data Display;
Check off Show Confidence Interval

Points should fall on a straight line on the normal probability plot (fat pencil test). t-Tests will still work as long as the data is not badly skewed.

Graphical Analysis

Dotplot, boxplot, etc.
Graph > Dotplot > With Groups
Graph > Boxplot > With Groups
Graph Variable is "Y";
Categorical Variable is "X"

Provides a picture of the data. Does the signal look large relative to the noise?

Study Centering

Paired t-Test
Stat > Basic Statistics > Paired t
First Sample is the "first sample";
Second Sample is the "second sample"
(Optional: Graphs Check Histogram of Differences, Individual Value Plot and Boxplots of Data)

H_o: Mean of the differences in the paired values = 0 (or reference value)

p-value = % chance mean of the differences = 0

Small p-value (<.05) → Difference between paired values ≠ 0 (or reference value)

```
                  N       Mean     StDev   SE Mean
Time Keeper 1    51    1.63059   0.39699   0.05559
Time Keeper 2    51    1.58706   0.40821   0.05716
Difference       51   0.043529  0.121849  0.017062

95% CI for mean difference:  (0.009259, 0.077800)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.55  P-Value = 0.014
```

Observed difference between Time Keeper 1 & Time Keeper 2 paired values

95% confident the average for the differences lies in this interval

t-statistic = Signal-to-Noise ratio

H_o: Mean of the differences in the paired values = 0

H_a: Mean of the differences in the paired values ≠ 0

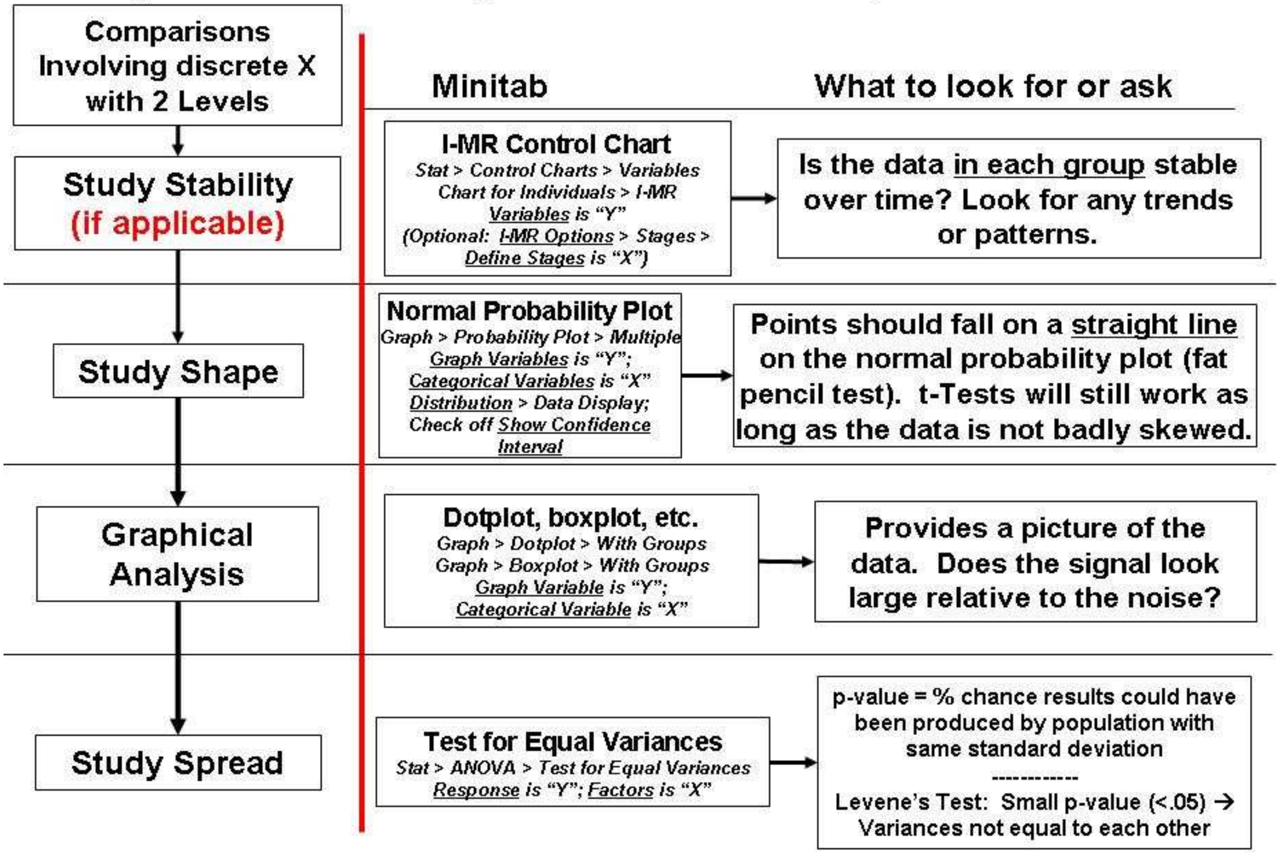
p-value = 1.4% chance the mean of the differences = 0. Therefore, Reject H_o.

Test for Equal Variances (a.k.a. Levene's Test)

Test for Equal Variance is used to compare the variability of a discrete input (X) with two or more levels (e.g. Supplier A and Supplier B) and a continuous output (Y).

- Test for Equal Variance makes two assumptions: data are stable and normal. Test for Equal Variances still performs well with moderate departures from normality**.**
- Sample size does not have to be equal.
- Variance testing requires a relatively large sample size – e.g. 20-30 samples. Smaller sample sizes can be used but the sensitivity of the test decreases. Failure to detect a difference with a small sample does not necessarily mean no difference exists but rather the sample may be too small. In the case where variability needs to be validated a good size sample must be obtained.
- See the following roadmap for how to analyze a Test for Equal Variance.

Analyze Roadmap – Test for Equal Variance



Comparisons Involving discrete X with 2 Levels

Minitab | **What to look for or ask**

Study Stability (if applicable)

I-MR Control Chart
Stat > Control Charts > Variables Chart for Individuals > I-MR
Variables is "Y"
(Optional: I-MR Options > Stages > Define Stages is "X")

→ Is the data in each group stable over time? Look for any trends or patterns.

Study Shape

Normal Probability Plot
Graph > Probability Plot > Multiple
Graph Variables is "Y";
Categorical Variables is "X"
Distribution > Data Display;
Check off Show Confidence Interval

→ Points should fall on a straight line on the normal probability plot (fat pencil test). t-Tests will still work as long as the data is not badly skewed.

Graphical Analysis

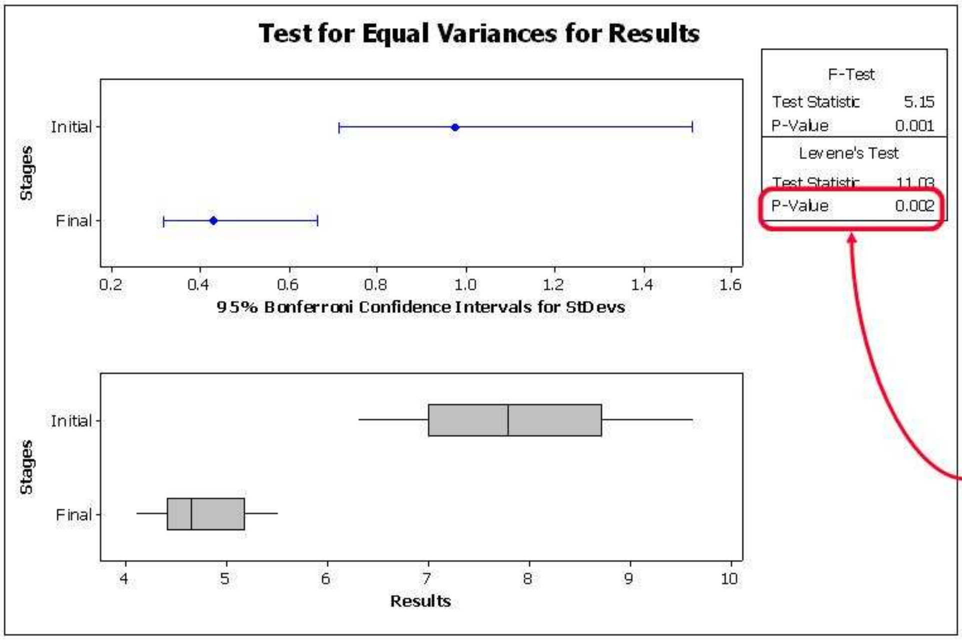
Dotplot, boxplot, etc.
Graph > Dotplot > With Groups
Graph > Boxplot > With Groups
Graph Variable is "Y";
Categorical Variable is "X"

→ Provides a picture of the data. Does the signal look large relative to the noise?

Study Spread

Test for Equal Variances
Stat > ANOVA > Test for Equal Variances
Response is "Y"; Factors is "X"

→ p-value = % chance results could have been produced by population with same standard deviation
----
Levene's Test: Small p-value (<.05) → Variances not equal to each other



H_o: Initial variance (or standard deviation) = Final variance (or standard deviation)

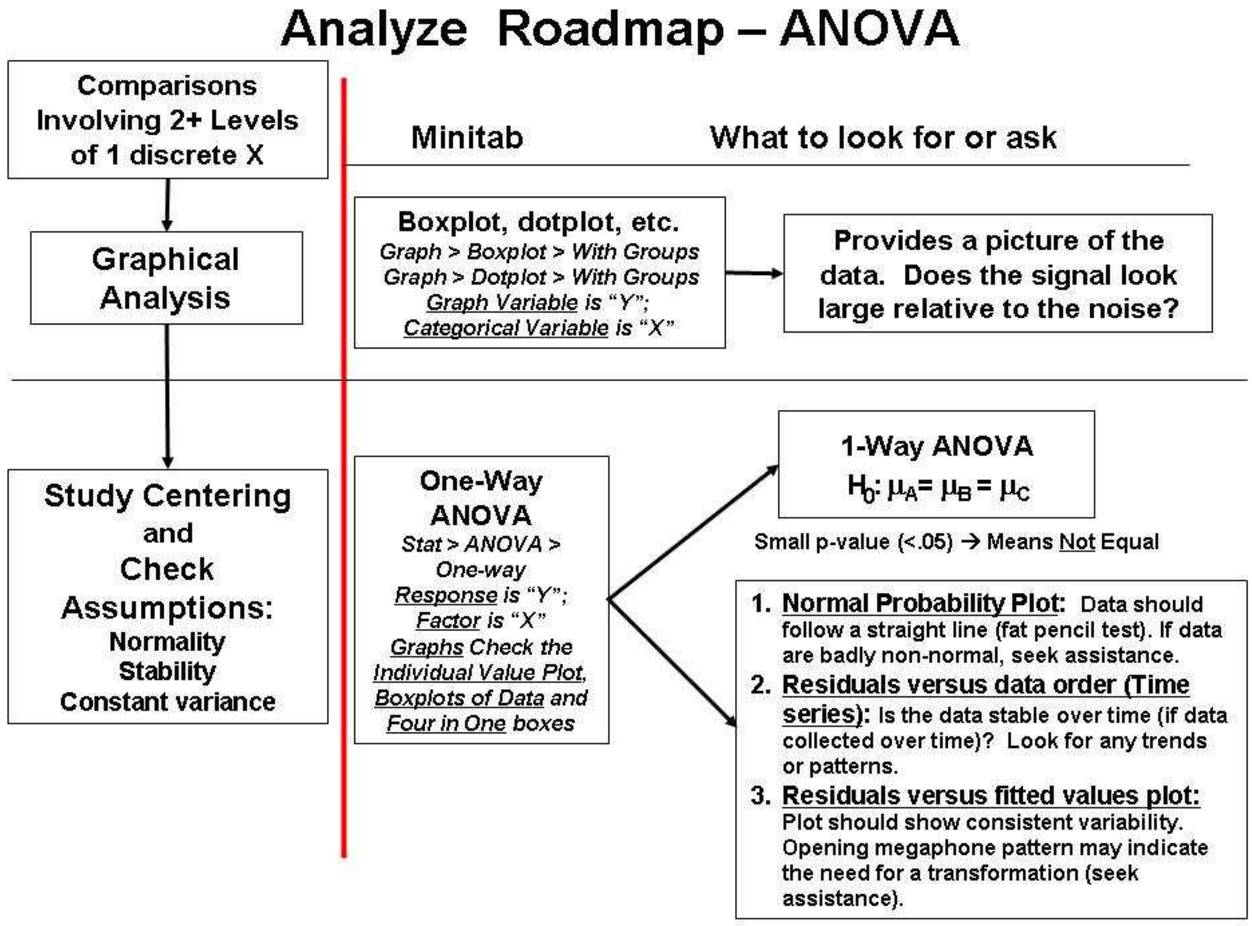
H_a: Initial variance (or standard deviation) ≠ Final variance (or standard deviation)

p-value = 2% chance variances are the same. Therefore, Reject H_o.

Analysis of Variance (ANOVA)

ANOVA is used to compare a discrete input (X) with two or more levels (e.g. Supplier A, Supplier B and Supplier C) and a continuous output (Y). ANOVA answers the question: is Supplier A mean = Supplier B mean = Supplier C mean?

- Residuals are the difference between what is observed and what is predicted.
  - ANOVA makes predictions for each factor level. Predicted value for an observation from a given level is the mean of all observations at that level.
  - Residual for a given observation is difference between that observation and its predicted value (Residual = Observed – Predicted).
  - Residuals analysis helps validate assumptions made in the analysis.
- Statistical assumptions are made:
  - Standard deviation is the same for each level of the factor.
  - Residuals should be normally distributed.
  - Responses are independent and normally distributed.
    - If data are collected over a very short time period there is a risk of dependent means.
    - Randomization and adequate sample sizes usually address this.
- ANOVA is very robust to moderate departures from normality.
- See "Residuals – Model Adequacy" for discussion on residuals.
- See the following roadmap for how to analyze an ANOVA test. See the following page for interpretations of the results.



Analyze Roadmap – ANOVA

Comparisons Involving 2+ Levels of 1 discrete X

Minitab | **What to look for or ask**

Graphical Analysis

Boxplot, dotplot, etc.
Graph > Boxplot > With Groups
Graph > Dotplot > With Groups
Graph Variable is "Y"; Categorical Variable is "X"

Provides a picture of the data. Does the signal look large relative to the noise?

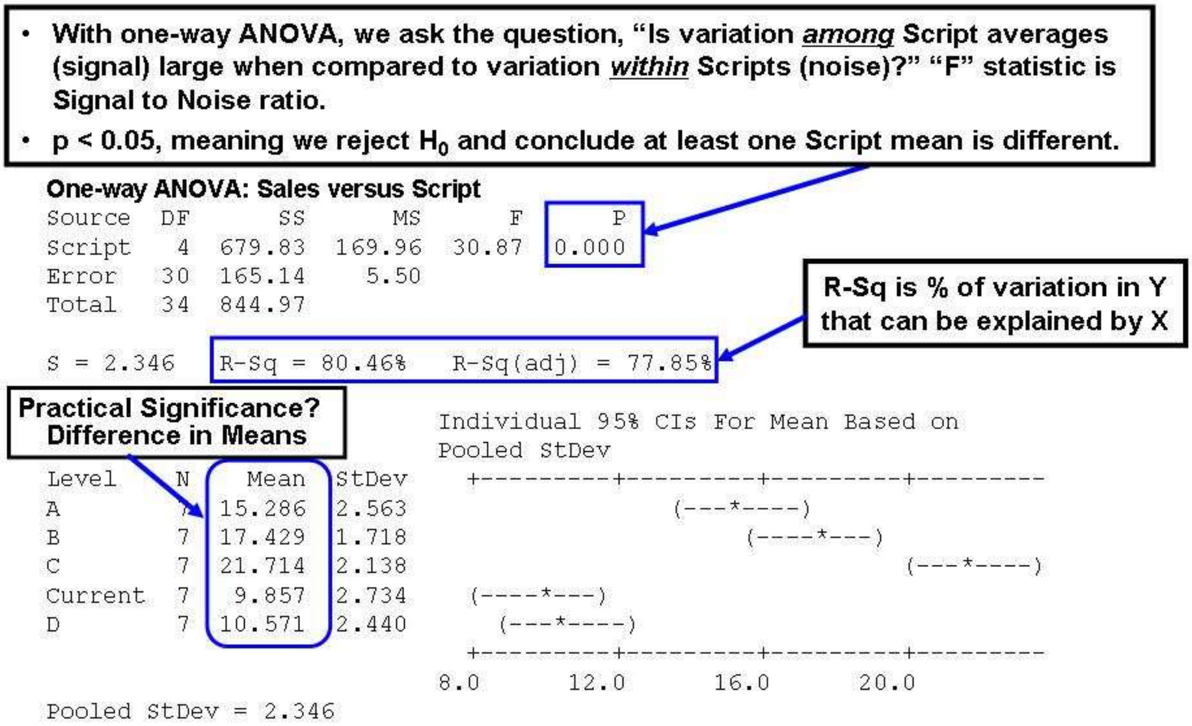
Study Centering and Check Assumptions:
Normality
Stability
Constant variance

One-Way ANOVA
Stat > ANOVA > One-way
Response is "Y"; Factor is "X"
Graphs Check the Individual Value Plot, Boxplots of Data and Four in One boxes

1-Way ANOVA
$H_0: \mu_A = \mu_B = \mu_C$

Small p-value (<.05) → Means Not Equal

1. **Normal Probability Plot:** Data should follow a straight line (fat pencil test). If data are badly non-normal, seek assistance.
2. **Residuals versus data order (Time series):** Is the data stable over time (if data collected over time)? Look for any trends or patterns.
3. **Residuals versus fitted values plot:** Plot should show consistent variability. Opening megaphone pattern may indicate the need for a transformation (seek assistance).



- With one-way ANOVA, we ask the question, "Is variation *among* Script averages (signal) large when compared to variation *within* Scripts (noise)?" "F" statistic is Signal to Noise ratio.
- $p < 0.05$, meaning we reject H_0 and conclude at least one Script mean is different.

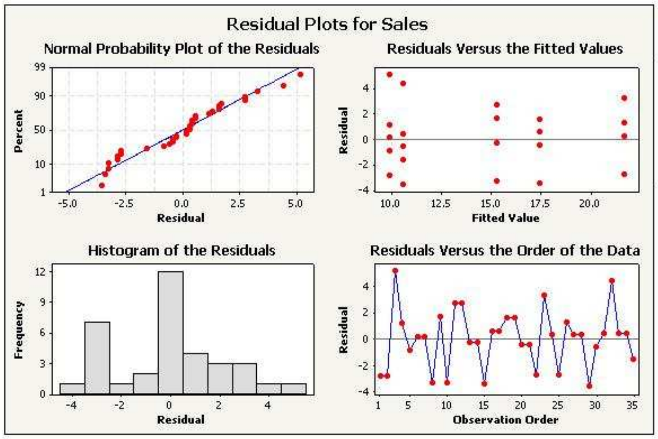
One-way ANOVA: Sales versus Script

```
Source  DF      SS      MS      F      P
Script   4  679.83  169.96  30.87  0.000
Error   30  165.14    5.50
Total   34  844.97

S = 2.346   R-Sq = 80.46%   R-Sq(adj) = 77.85%

                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level    N    Mean  StDev  +---------+---------+---------+---------
A        7  15.286  2.563                (---*----)
B        7  17.429  1.718                     (----*---)
C        7  21.714  2.138                                (---*----)
Current  7   9.857  2.734  (----*---)
D        7  10.571  2.440    (---*----)
                           +---------+---------+---------+---------
                         8.0      12.0      16.0      20.0

Pooled StDev = 2.346
```

R-Sq is % of variation in Y that can be explained by X

Practical Significance? Difference in Means

Residual Analysis



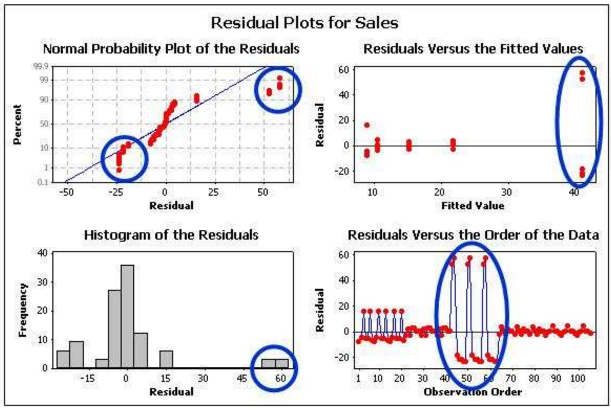
Fat pencil test – Normal plot should form a straight line

Should have equal spread in vertical direction

Histogram should look normally distributed

Should look random – no special causes

Poor Residual Analysis



Fat pencil test – Data not a very straight line

Unequal spread in vertical direction

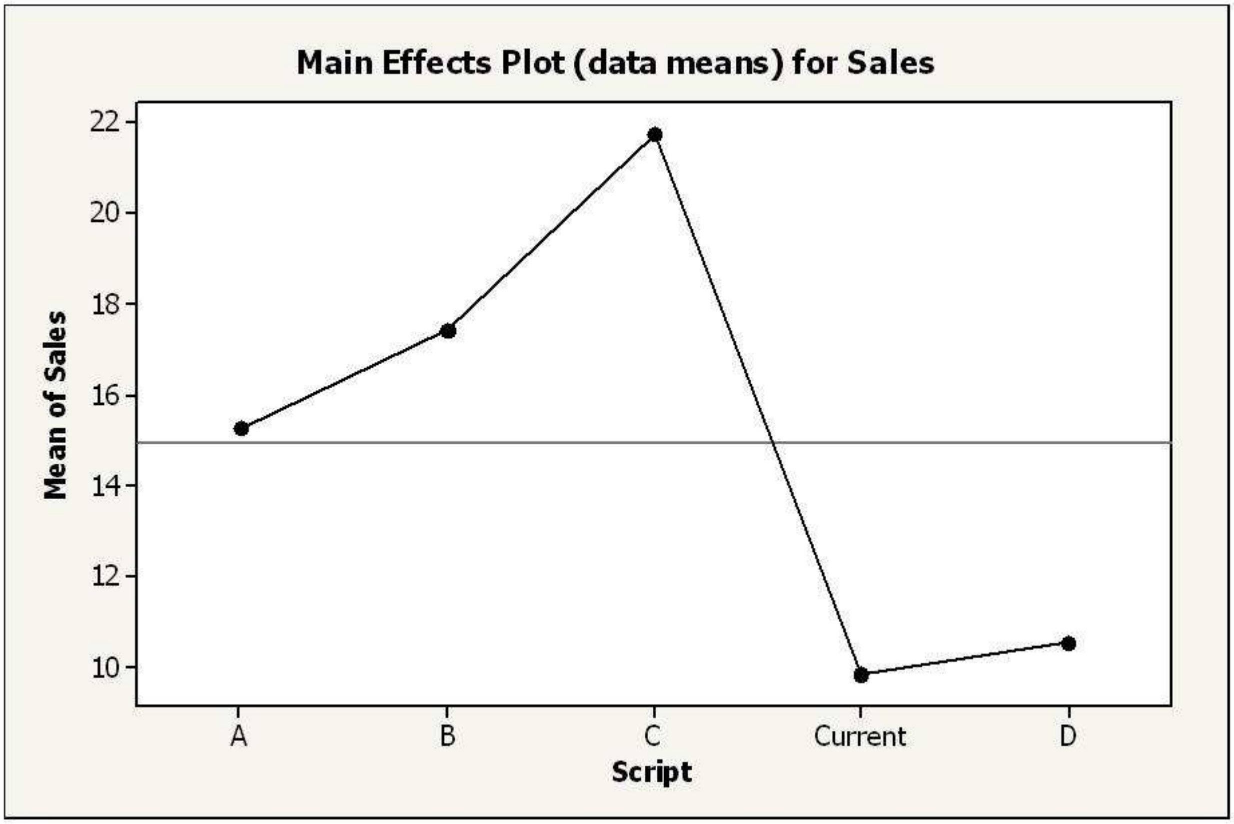
Histogram – some data points are skewed

Does not appear random - special causes exist

Main Effects Plot

The Main Effects plot is a good graphical representation of the ANOVA results. It allows comparisons of a discrete input (X) with two or more levels (e.g. Supplier A, Supplier B and Supplier C) to a continuous output (Y). The Main Effects plot is similar to a box plot but with less detail.

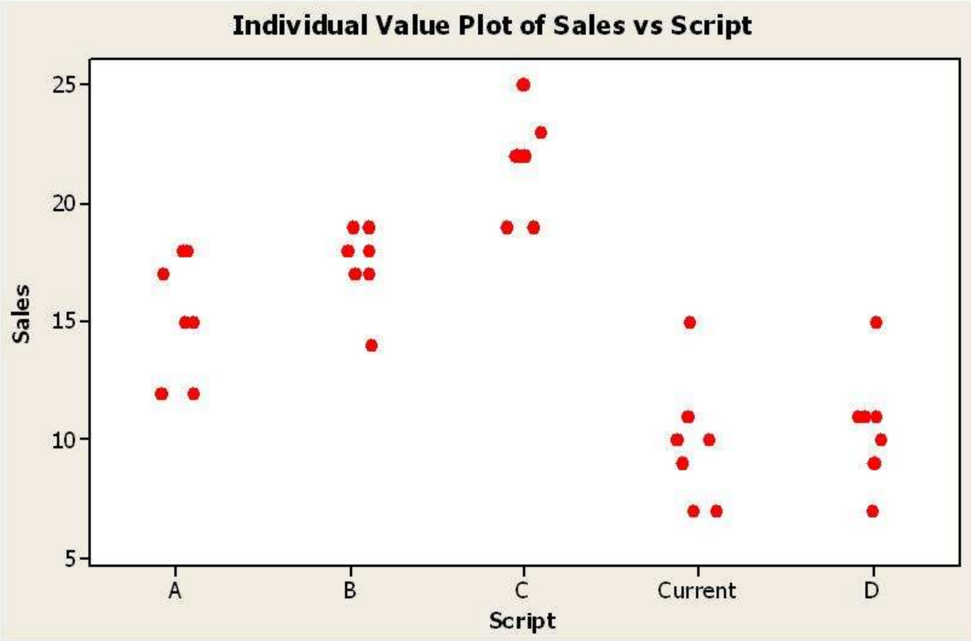
- ***In Minitab:*** To create a Main Effects plot in Minitab:
  Stat > ANOVA > Main Effects Plot; Response is "Continuous Y"; Factors is "Discrete X"
- Cautions:
  - Small samples can produce misleading results. Always do a dotplot or individual value plot after doing a Main Effects plot.
  - Don't create a Main Effects plots with continuous Xs. The X-axis on a Main Effects plot spaces all values equally, which can distort relationship between continuous Xs and Ys. Use scatterplots instead.



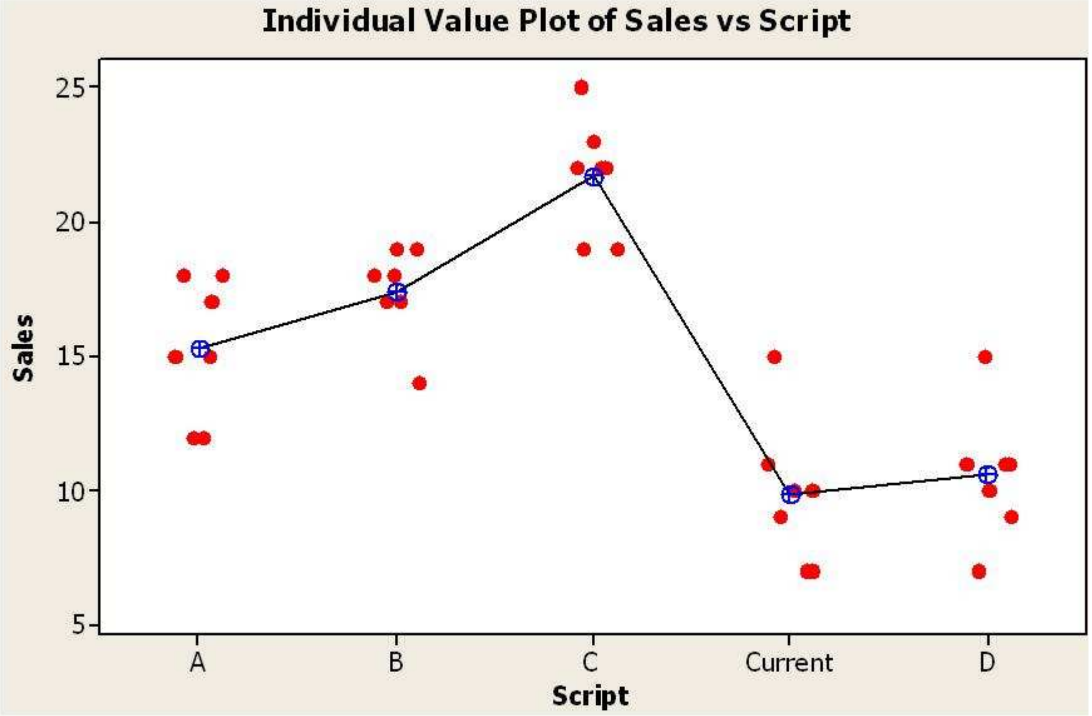
Individual Value Plot

The Individual Value plot is another graphical representation of the ANOVA results. It allows comparisons of a discrete input (X) with two or more levels (e.g. Supplier A, Supplier B and Supplier C) to a continuous output (Y). The Individual Value plot is similar to a dot plot but tilted on its side.

- ***In Minitab:*** To create an Individual Value Plot in Minitab either select it as a graph option when running an ANOVA test or complete the following steps:
  Graph > Individual Value Plot > One Y; With Groups > Graph Variables is "Continuous Y"; Categorical Variables for Grouping is "Discrete X"



Please note: If the Individual Value Plot is done as listed above, the graph above will be displayed. If the Individual Value Plot is selected as a graph option within ANOVA, the following graph will appear (difference in graphs is the means are identified and connected).

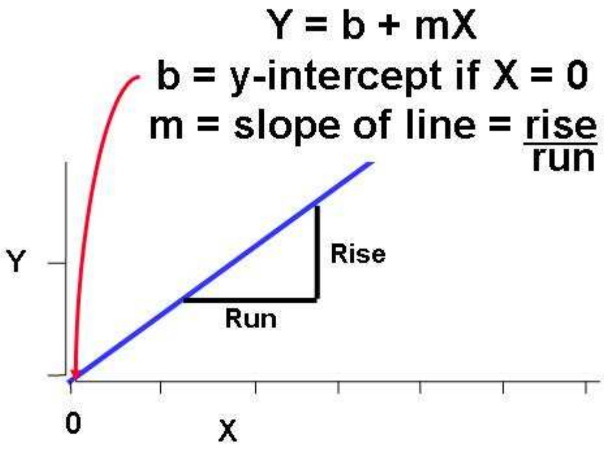


Regression/Correlation

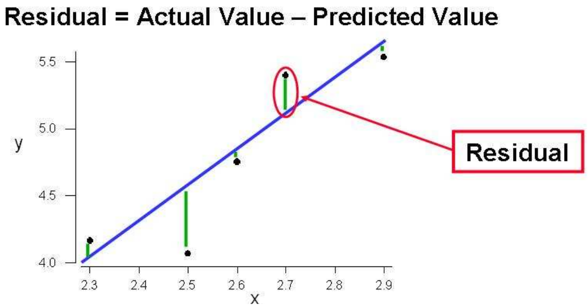
Correlation is the strength of the linear relationship between two continuous variables. (Correlation does not prove causation.)

- Regression (also known as Correlation) analysis is a statistical technique used to investigate and model the relationship between continuous variables.
    - Simple Linear Regression relates one continuous X with one continuous Y.
    - Multiple Linear Regression relates more than one continuous X with more than one continuous Y. The Matrix Plot can be used to visually assess possible relationships.

- Model **parameters** (e.g., estimates of slope and intercept) are obtained using the method of **least squares**.
    - If there is no correlation, the best fit is $y = \bar{y}$
    - The line created by Minitab has the formula Y = b + mX



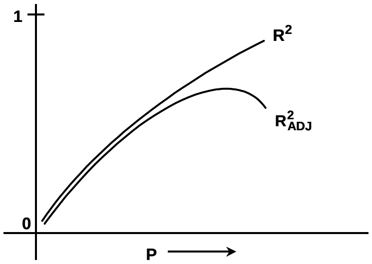
Residuals – Model Adequacy


Residual = Actual Value – Predicted Value

- Model **adequacy** is checked by reviewing the quality of the fit and checking **residuals.**
    - Residual is actual value minus predicted value (the line). Residuals may be negative or positive.
    - Residuals are used to check for model adequacy because they tell us if key assumptions are met.
    - Residuals should have constant variance, be normally distributed, and be in control over time.
    - Residual evaluation is an essential step in a regression analysis. It gives you a warning sign if the fitted model is not appropriate.

$$R^2 = \frac{SS_{Regression}}{SS_{Total}}$$

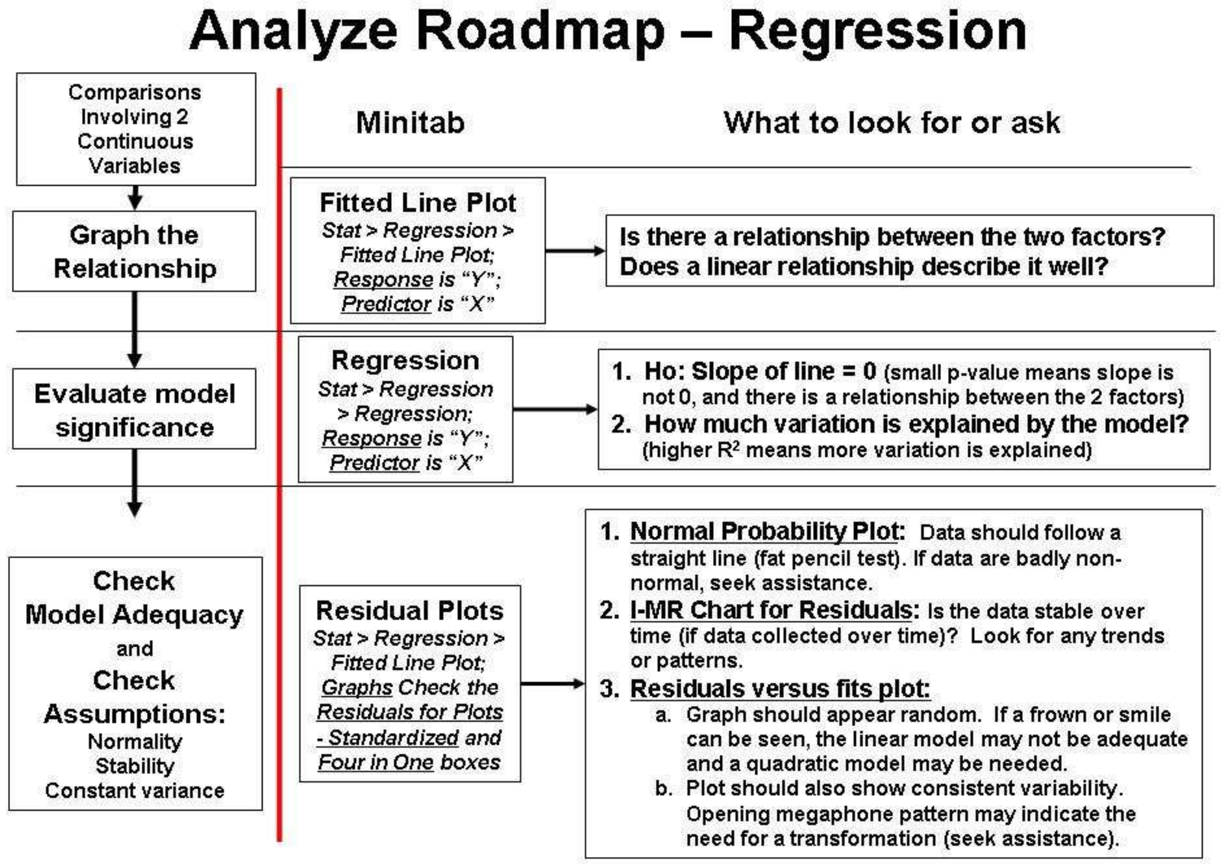
- **R^2** is the Coefficient of Determination – the proportion of variability explained by the regression model.
    - R^2 is a useful measure for assessing the fit (higher is better).
    - High R^2 does not guarantee a good fit! Always graph the data.
    - Low R^2 does not mean the variable is unimportant! As long as p-value is low, only means there are additional important X's.
    - How high R^2 should be depends upon type of process and data being studied. Greater than 70% is often considered good for transactional projects.



- **$R^2_{adjusted}$** Statistic:
    - R^2 increases when any factor is added to the model, even if the factor does not explain a significant amount of variation.
    - $R^2_{adjusted}$ adds a penalty for keeping insignificant factors in the model.
    - Note relationship between R^2 and $R^2_{adjusted}$ as the number of factors in the model increases.

- **Higher-order models** of Regression – If the Residuals versus Fits plot shows a parabolic shape (e.g. smile or frown), a higher order model may be needed.
    - Minitab's Fitted Line Plot will allow a quadratic term. The fitted line plot also allows a cubic term, but it often results in "overfitting" the data. Do not use it without consulting your Black Belt or Coach.

- **Pitfalls** of Regression:
  - Do not **extrapolate** to predict Y at levels of X that haven't been studied (e.g. studied advertising spend between 100 and 200 – can not extrapolate what sales will be at advertising spend of 400)!! You can use the model to predict for values within the area of study.
  - Watch for the influence of a few **outlier** values.
    - If the outlier is a **bad value**, then the model is wrong. However, if the outlier is real, it should not be removed. It is a useful piece of data on the process. Refer to your notes or other information to understand the outlier. Evaluate model with and without outlier to determine its effect.
    - If the outlier is an **extreme value**, it may be artificially influencing the results. Refer to your notes or other information to understand the extreme value. Evaluate model with and without the extreme value to determine its effect. If your conclusions change significantly, the point is too influential and should be removed. Also be careful about interpreting the results when there are large gaps in the X's that cause the extreme values.
  - Be aware of **"nonsense" relationships** or wrong conclusions. The predictor input "X" needs to be known to evaluate the response output "Y".
  - **Poor MSA** on input (X). Just like a good MSA is important on the outputs, good data is needed for the inputs.



Analyze Roadmap – Regression

Comparisons Involving 2 Continuous Variables

Minitab | **What to look for or ask**

Graph the Relationship

Fitted Line Plot
Stat > Regression > Fitted Line Plot; <u>Response</u> is "Y"; <u>Predictor</u> is "X"

Is there a relationship between the two factors?
Does a linear relationship describe it well?

Evaluate model significance

Regression
Stat > Regression > Regression; <u>Response</u> is "Y"; <u>Predictor</u> is "X"

1. **Ho: Slope of line = 0** (small p-value means slope is not 0, and there is a relationship between the 2 factors)
2. **How much variation is explained by the model?** (higher R^2 means more variation is explained)

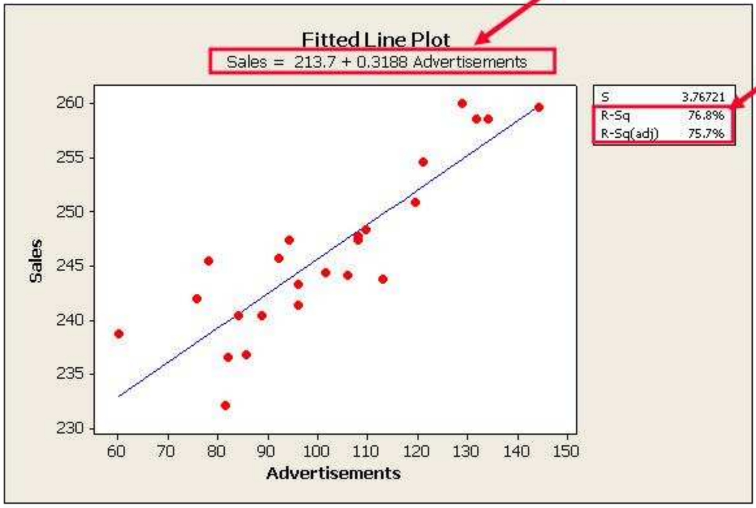
Check Model Adequacy and **Check Assumptions:**
Normality
Stability
Constant variance

Residual Plots
Stat > Regression > Fitted Line Plot; <u>Graphs</u> Check the <u>Residuals for Plots - Standardized</u> and <u>Four in One</u> boxes

1. **<u>Normal Probability Plot</u>:** Data should follow a straight line (fat pencil test). If data are badly non-normal, seek assistance.
2. **<u>I-MR Chart for Residuals</u>:** Is the data stable over time (if data collected over time)? Look for any trends or patterns.
3. **<u>Residuals versus fits plot:</u>**
   a. Graph should appear random. If a frown or smile can be seen, the linear model may not be adequate and a quadratic model may be needed.
   b. Plot should also show consistent variability. Opening megaphone pattern may indicate the need for a transformation (seek assistance).

Regression – Fitted Line Plot

Linear equation can be used to predict average values for sales for different levels of advertising.



R-Sq shows amount of variability explained by linear equation. For example, 76.8% of sales can be explained by amount of money spent on advertising. Remaining 23.2% is due to other X's.

R-Sq(adj) shows amount of variability explained by linear equation with a reduction for each term (X).

Regression – Minitab Session Output

```
The regression equation is
Sales = 214 + 0.319 Advertisements
  Y   =  b  +  m          X

Predictor                 Coef   SE Coef      T      P
Constant               213.714     3.879  55.09  0.000
Advertisements (X)     0.31880   0.03736   8.53  0.000

S = 3.76721    R-Sq = 76.8%    R-Sq(adj) = 75.7%

Analysis of Variance

Source          DF      SS      MS      F      P
Regression       1  1033.7  1033.7  72.83  0.000
Residual Error  22   312.2    14.2
Total           23  1345.9
```

H_o: Slope = 0

H_a: Slope ≠ 0

p-value < 0.05

Therefore, slope of regression line is not equal to zero.

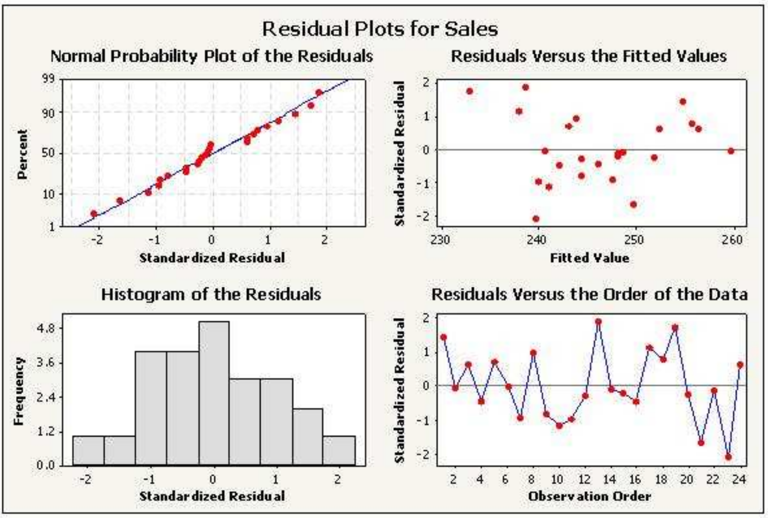
Note: If more than one X was studied (e.g. advertisement dollars and number of demonstrations), a separate p-value would have been given for each X studied.

p-value < 0.05

Therefore, slope of regression line is not equal to zero.

Note: Regardless of how many X's are studied, one p-value is given for the entire equation.

Residual Analysis



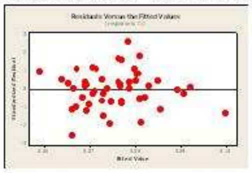
Fat pencil test – Normal plot should form a straight line.

Histogram should look normally distributed.

Should have equal spread in vertical direction. Look for patterns. (See pictures below.)

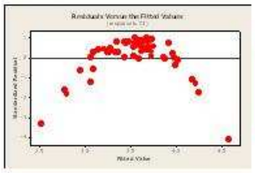
- Should look random – no special causes.
- Residuals that appear out of control should be studied further.
- Possible out-of-control issues include measurement systems error, incorrect data entry, or process upset
- This plot is only relevant if the data are entered in time order.

Residuals vs. Fits



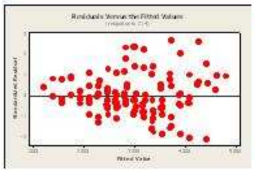
> Residuals have no obvious pattern. Variation is consistent throughout.

> *Model is adequate*



> Residuals show curvature; may need a higher order model

> *Model is inadequate – try a higher order model (e.g. quadratic)*

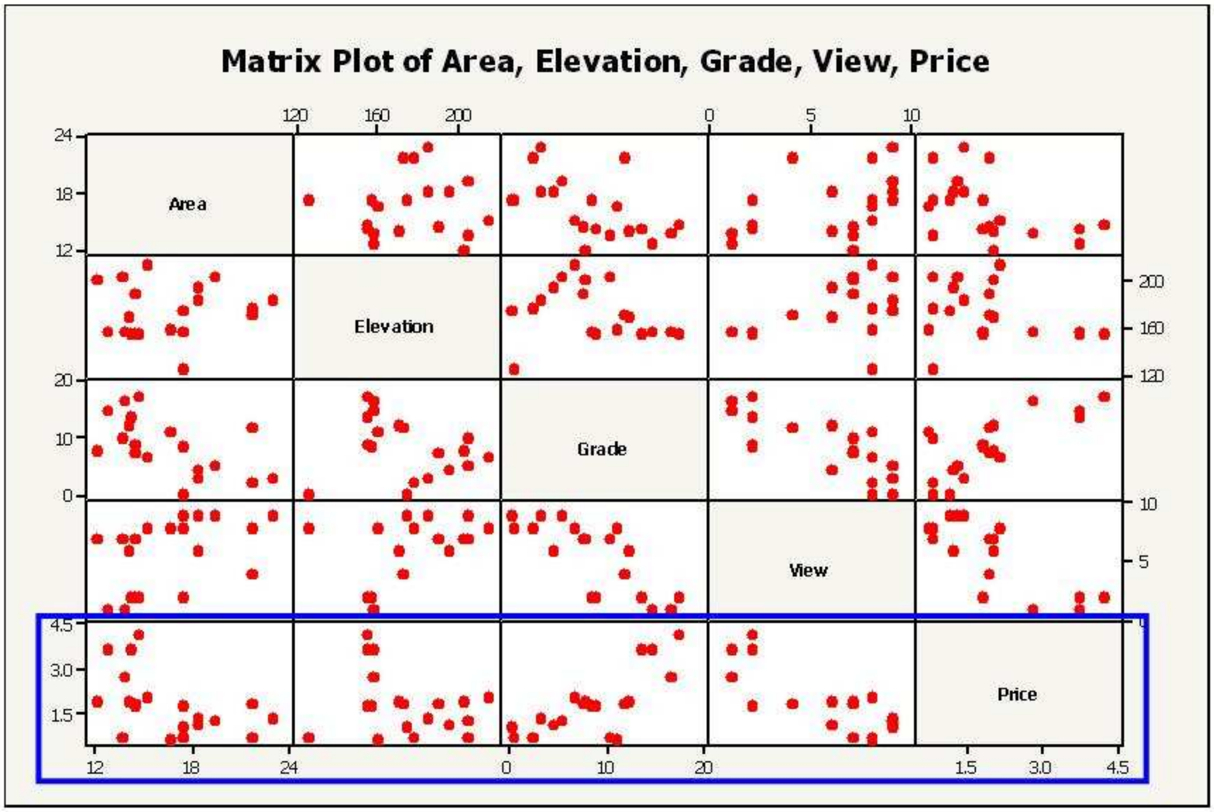


> Residuals show a funnel pattern; variance increases as Y increases

> *Model is inadequate – see coach!*

Matrix Plot

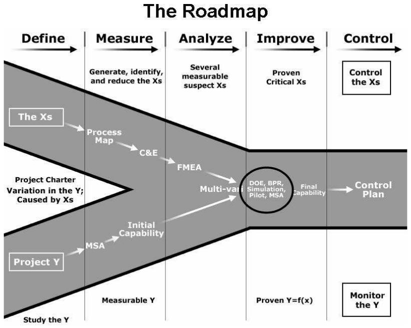
- The Matrix plot is a good tool to visually assess possible relationships between multiple continuous inputs (X's) and outputs (Y's). The Matrix plot shows scatterplots of all continuous variables versus . each other. It can guide you to which continuous variables to include in a regression analysis.
- ***In Minitab:*** To create a Matrix plot in Minitab:
  Graph > Matrix Plot > Simple; Graph Variables are all of the continuous variables you wish to compare
- ***Results:*** Read the Matrix plot by finding the intersection of two continuous variables.



Analyze Phase – Completion Checklist

☐ Failure modes of X’s, suspected critical X’s, and relationships between X’s and Y’s identified and validated with data.
☐ Possible improvement ideas beginning to formulate.
☐ Project charter updated to reflect new information.
☐ Subject matter experts involved on project team.
☐ If you have a question, ASK!

V. Improve



Improve Phase Purpose:

- Quantify the relationship between the critical inputs (X's) and outputs (Y's).
- To prove which Xs produce variability seen in Y's.
- To test potential solutions before implementing on a grand scale.
- To verify that the proposed solutions are effective and/or to determine which options are needed.

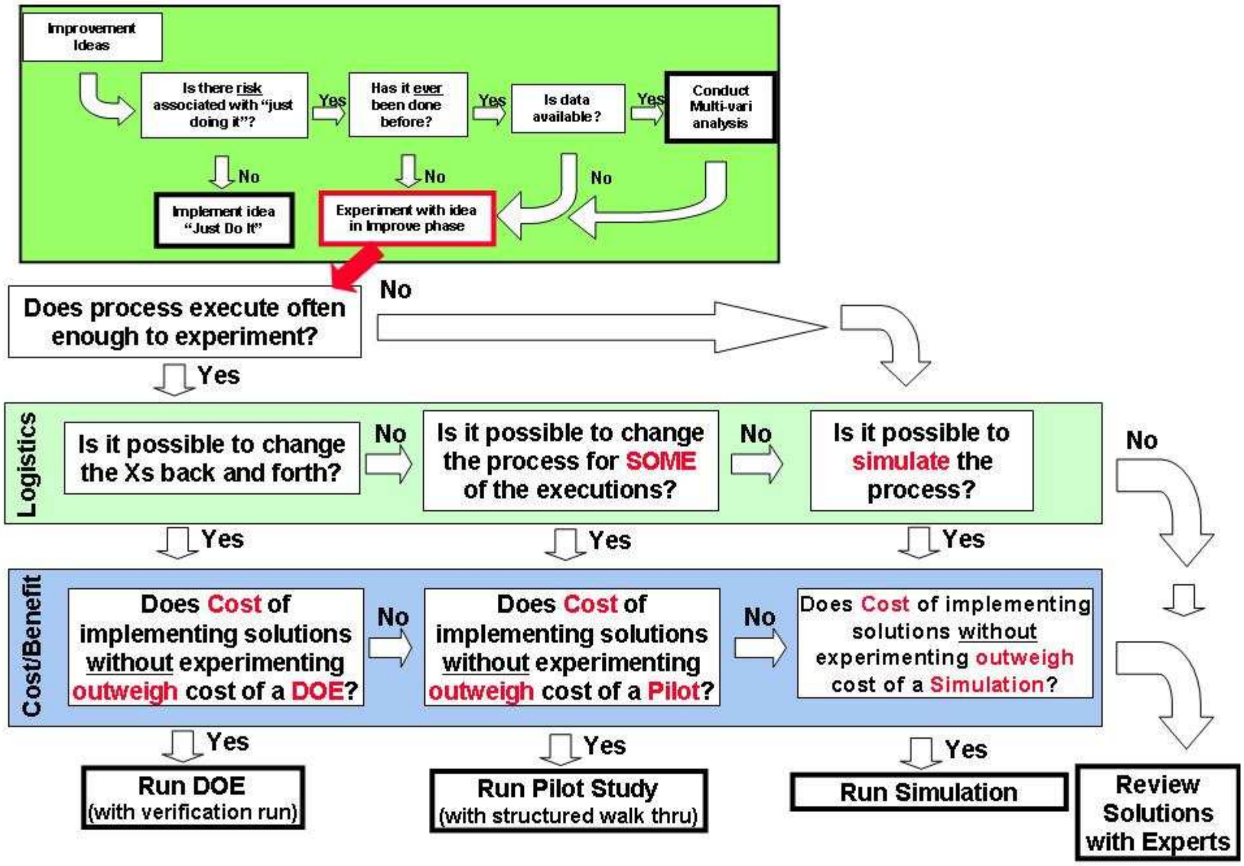
Improve Phase Goals:

- For the suspected critical inputs (X's), identify possible improvement options.
- Actively experiment to manipulate the inputs and determine their effects on the outputs (Y's). "Critical" variables are identified during this process.
- "Experiments" are the backbone of this phase. Can include pilots, simulations, DOEs, etc.
- Identify "Critical" inputs to control. Fix X's at optimum settings. Adjust X's to control Y.

A. Potential Risks of Skipping Improve Phase

Due to various risks associated with implementing most solutions, the Improve phase should not be skipped. Need to determine if the potential benefit outweighs the risks:

- ***Time*** – Amount of time required to create, implement and maintain the solution
- ***Cost*** – Financial investments associated with implementing the solution
- ***Complexity*** – Solution may be intricate or interwoven with other processes. Understand if change will slow people's jobs or make it harder to monitor.
- ***Backfire Potential*** – As a result of the solutions implemented, there could be unexpected, undesired results.



B. Potential Tools for the Improve Phase

There are several tools available for this phase, depending upon the nature of your project. (See the appropriate sections for more details.)

- ***Just Do It!*** (Potential Quick Hit)
  - What it is: Implementation of low risk ideas
  - When to use: Only when risks are extremely low
- ***Business Process Redesign*** (BPR)
  - What it is: Use of additional tools to completely overhaul the process – significantly changing how work is done.
  - When to use: When current process is so badly broken or flawed that only solution is to create a new process. (See BPR section).
- ***Lean "Improve" Tools***
  - What it is: Set of tools to improve process flow or eliminate waste
  - When to use: When trying to improve the flow of a process or eliminate "waste"
- ***Structured Walkthrough***
  - What it is: Role play a real-life situation with proposed changes.
  - When to use: Use before a pilot to validate a new or redesigned process. (See BPR section.)
- ***Simulation***
  - What it is: Formal modeling of new process with software.
  - When to use: When you can't afford to run a formal experiment or pilot study and data is available. (See Simulation section.)
- ***Pilot Study***
  - What it is: A small scale implementation of proposed solution.
  - When to use: If risks (time, cost, complexity, potential backfire) are too high to proceed directly to full implementation of improvement. (See Pilot Study section.)
- ***Design of Experiments (DOE)***
  - What it is: A statistically structured plan for changing X's and measuring impact on Y's
  - When to use:
    - Multiple solution options exist
    - Risk in implementing on a small scale
    - Can measure impact of X's on Y in a reasonable time frame
    - See Designed Experiment section.

C. Business Process Redesign

What is Business Process Redesign (BPR)?

Scrapping or significantly changing an existing process. BPR is about flow or function of X's through DMAIC. "Disconnects" are identified as flow or function "problems."

- Process Re-design – Current work process does not meet project goal.
    - BPR may be understood from the start of the project. A paradigm shift or system change is required – more than just a few inputs (X's) need to be modified.
    - BPR may be identified midway through the project. Discover the inputs (X's) are not enough to influence the change in Y or the desired outcome.
- Process Design – Desired work process does not exist.
    - May be the situation is a rare case.
    - May be a terminal Y – task oriented projects with business case supporting decision.

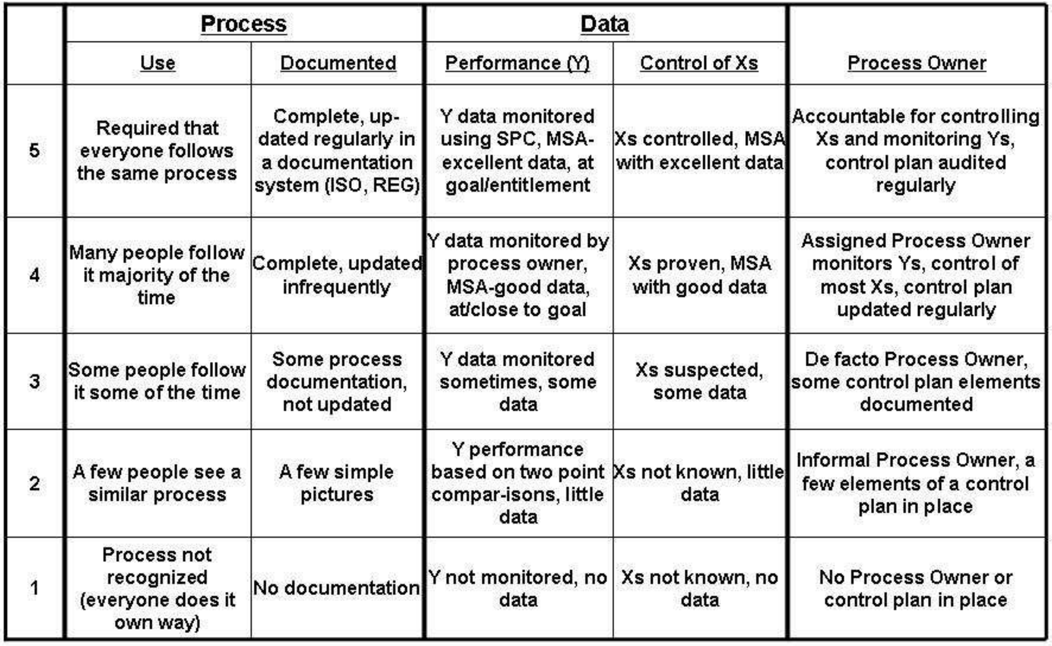
When would I use BPR?

When processes are missing, ill-defined, misunderstood, undocumented, largely ignored, flawed, broken, irreparable, maxed-out, fruitless, or when we can't get there from here.

How do I determine if I need BPR?

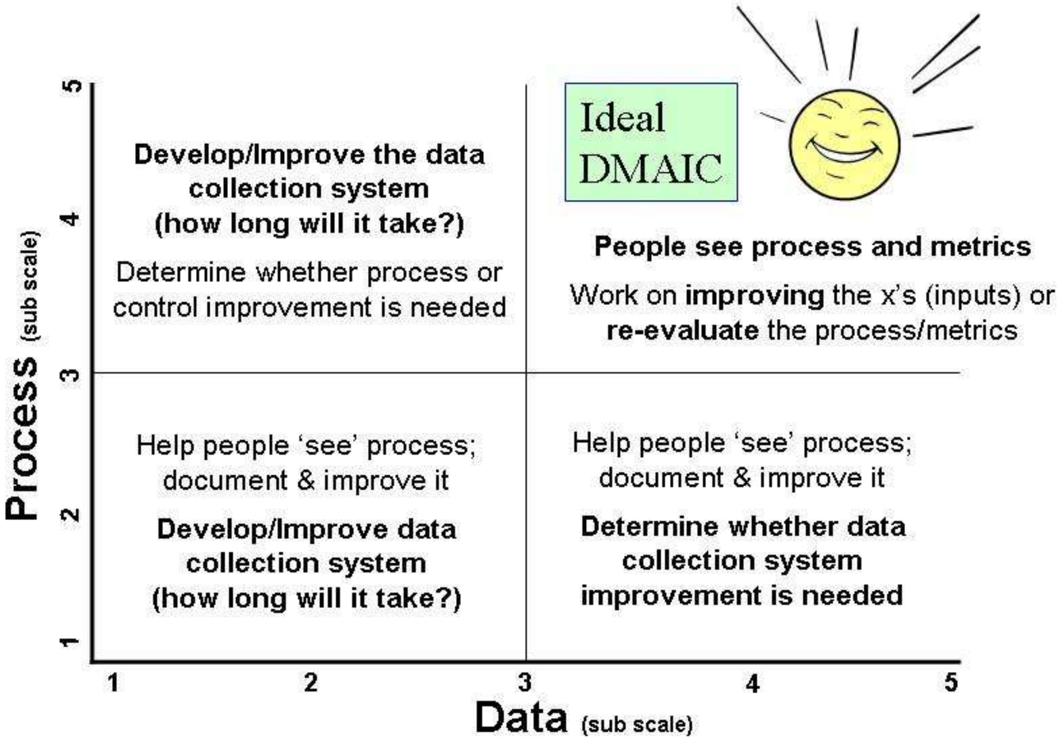
Process Improvement Matrix (PIM): Use this chart with project team to evaluate the overall process.

1. Use the definitions in each column (Use, Documented, Performance, Control of X's, Process Owner) to rate the process you are trying to improve. The lower the score per column, the more chaotic things are and the more important it is to fix it.
2. Take the scores for each grouping (e.g. Process, Data, Process Owner) and average them to determine an overall score for your current process. The lower the score, the more likely you'll be redesigning your process versus doing a "less complex" process improvement. Note: Regardless of the situation, every process must have a process owner!



	Process		Data		Process Owner
	Use	Documented	Performance (Y)	Control of Xs	
5	Required that everyone follows the same process	Complete, up-dated regularly in a documentation system (ISO, REG)	Y data monitored using SPC, MSA-excellent data, at goal/entitlement	Xs controlled, MSA with excellent data	Accountable for controlling Xs and monitoring Ys, control plan audited regularly
4	Many people follow it majority of the time	Complete, updated infrequently	Y data monitored by process owner, MSA-good data, at/close to goal	Xs proven, MSA with good data	Assigned Process Owner monitors Ys, control of most Xs, control plan updated regularly
3	Some people follow it some of the time	Some process documentation, not updated	Y data monitored sometimes, some data	Xs suspected, some data	De facto Process Owner, some control plan elements documented
2	A few people see a similar process	A few simple pictures	Y performance based on two point compar-isons, little data	Xs not known, little data	Informal Process Owner, a few elements of a control plan in place
1	Process not recognized (everyone does it own way)	No documentation	Y not monitored, no data	Xs not known, no data	No Process Owner or control plan in place

Process Action based on score: (overall process score)	**Data Action based on score:** (Y's and X's score)
5 – improve process only if a must do (e.g. customer, legal, $'s) 4 – work on only if bridge to entitlement has cost / benefit 3 – classic DMAIC process improvement project 2 – process redesign 1 – process design/creation (see the work as a process)	5 – use data as is 4 – improve only if necessary 3 – improve measurement / data collection system 2 – re-design measurement / data collection system 1 – design/create measurement / data collection system



Develop/Improve the data collection system (how long will it take?)

Determine whether process or control improvement is needed

People see process and metrics

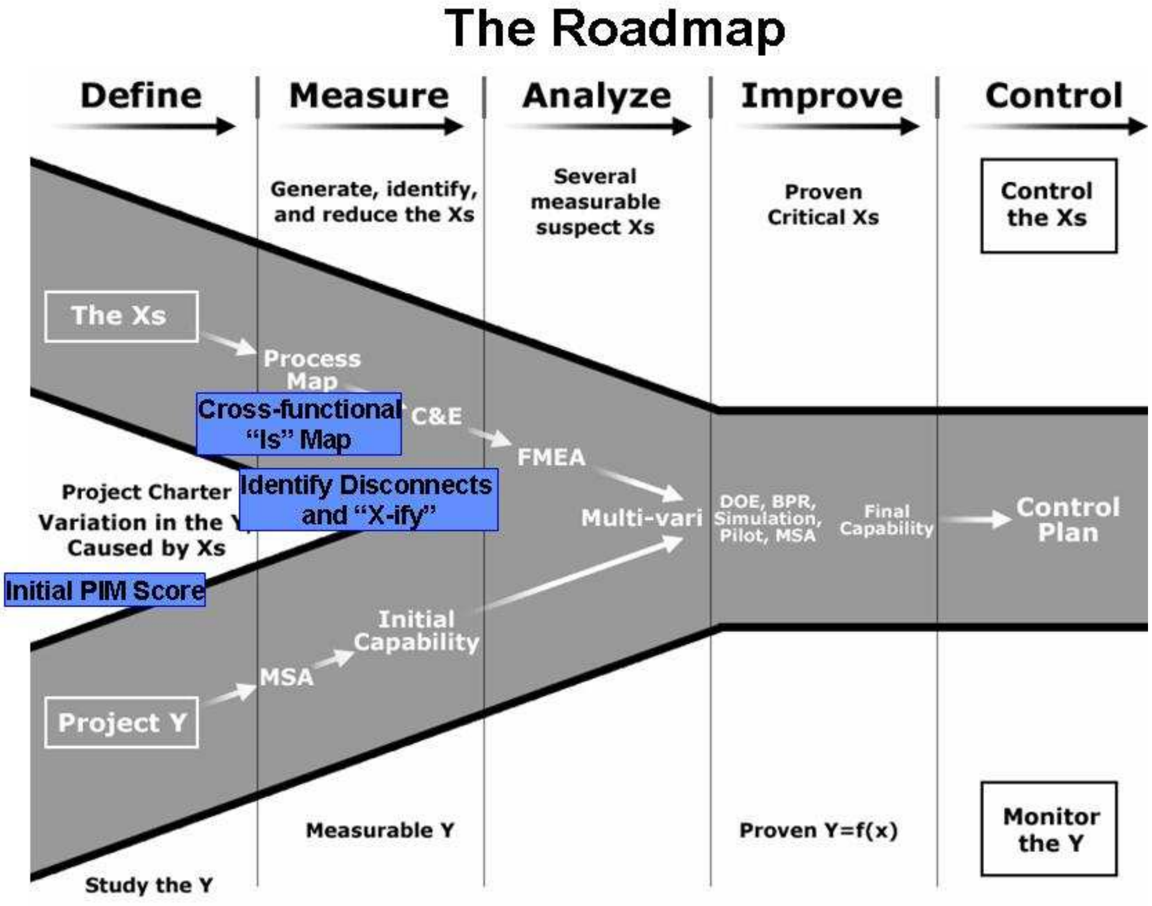
Work on **improving** the x's (inputs) or **re-evaluate** the process/metrics

Help people 'see' process; document & improve it

Develop/Improve data collection system (how long will it take?)

Help people 'see' process; document & improve it

Determine whether data collection system improvement is needed



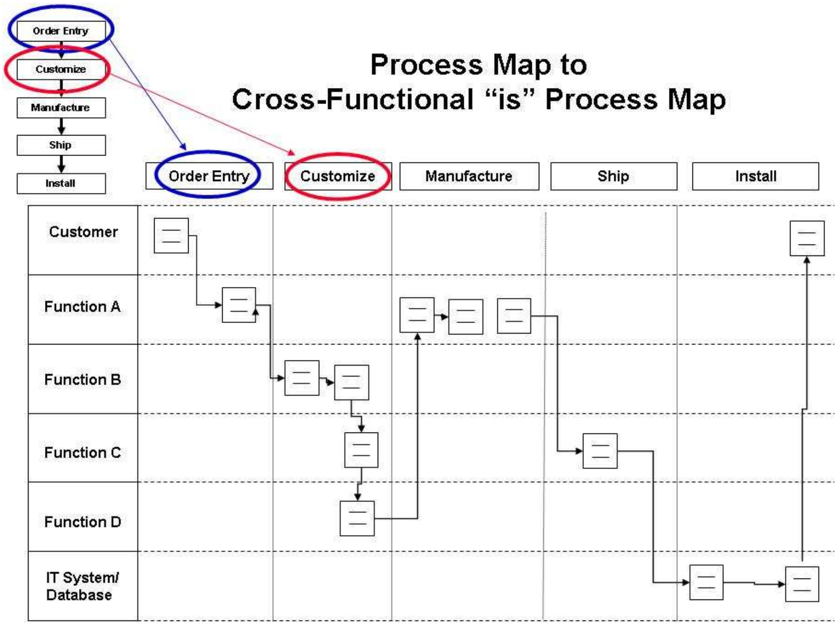
BPR Maps

- **Process Map** – Same as complete in regular DMAIC projects.
- **SIPOC –** Same layout as the regular Process Map but it includes the Supplier of the Inputs and the Customer of the Outputs.
  - Shows the "touch points" in which all processes are connected. Helps us understand issues when considering process improvements. Helps us understand who are the customers and their requirements.
  - Clarifies who provides or receives input/output:
    Supplier: who provides input (X)
    Inputs: nouns showing what is needed to complete the step
    Process Step: verb that describes what happens
    Outputs: nouns that describe what the step will deliver
    Customers: who receives benefit of the step's output (Y)

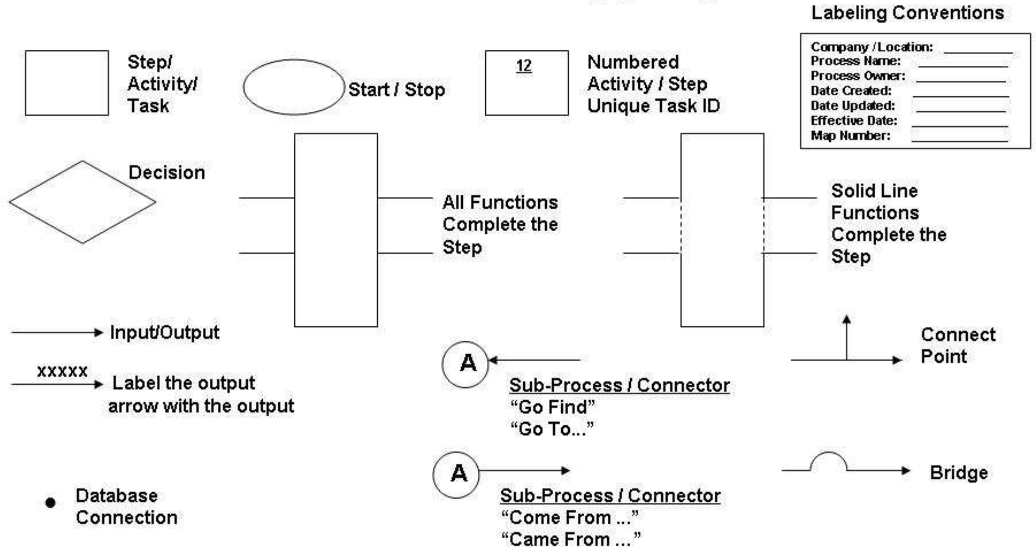
- **Cross-functional maps** (Swim lane map) – Shows how functions, departments, groups or individuals take inputs through the process steps, and through the organization, to produce outputs. Each step from the process map is broken into the individual tasks and placed in the appropriate function's row.

- **Recommend start** with Process Map to create "Is map":
  - Can use one method to create other. Top row of cross-functional map = boxes down column of process map.
  - Process Map is required in order to identify critical X's beyond process improvement needs and feeds the C&E, FMEA, etc….
  - Cross-functional map process disconnects can be X-ified to combine with process map critical X's into C&E, FMEA, etc….

- **Purpose** of each map:
  - Process Map – focuses on inputs
    - Identifies inputs and outputs, but not how they flow through the organization.
    - DMAIC identifies critical Xs that control variability of critical Y(s).
  - Cross-functional Map – focuses on what do with inputs
    - How the functions (departments, groups or individuals) move the inputs through process steps and through the organization to produce outputs.
    - Identifies disconnects that can be X-ified



Basic Cross-Functional Mapping Conventions



Process Disconnects

- **What are they?** Anything that negatively impacts effectiveness or efficiency of a process. E.g. pain to customer, incorrect data, slow process, rework, parallel paths.
- **What are sources?** Internal suppliers and customers. External suppliers and customers.
- **What are types?** Process steps, process flow, and measurements systems.
- **How do I document?** Typically documented on "IS" maps with results shown on SHOULD maps. Cross-functional maps usually are critical for disconnect identification and communication.
- **What are common disconnects?**

Inputs	Tasks	Outputs	Levels
• Missing or late • Not needed • From wrong suppliers • Not meeting expectations (Quality, cost, timeliness)	• Missing • Value adding • Correct resource • Correct timing • Bottleneck	• Not needed • Missing or late • To wrong customers • Not meeting expectations (external, internal)	• Overall Organization o Strategy o Policy o Organizational Structure • Individual Process o Information Flow o Process Flow o Input/Supplier • Job or Task o Process o Execution

- **What do I do with disconnects?**
  - Disconnects most often describe a Failure Mode of an X.
  - In order to take disconnects into C&E they need to be stated as an X.
  - Those left over are usually organization issues (eg. policies, business rules, established norms).
  - A few disconnects may be difficult to turn into Xs and take into C&E. These need to be reviewed carefully to see if anything needs to be put in place to handle them.
- **How do I bring disconnects to the FMEA?**
  - Options include:
    1. Prioritize all inputs (Xs) and disconnects in same C&E and bring larger number forward (e.g. 7-10) to FMEA.
    2. Prioritize all inputs (Xs) on one C&E, and all disconnects in separate C&E. Bring forward top from each C&E. E.g. top 4 Xs and top 7 Disconnects.
    3. Bring all disconnects directly to FMEA (no stopping at C&E with Disconnects). Still do C&E on all inputs (Xs).

Create Should Map

How to get from the current “is” process to the process we **want** it to be:

1. Collect data on top “IS” X’s and disconnects for Multi-Vari analysis. **Goal**: Validate if X’s and disconnects are important to include/improve upon in “Should” process.
2. Identify “Should” process.
   - Remember X’s and disconnects already identified. Include skills needed, key measurements, decisions, etc.
   - Complete cross-functional process map and RACI Matrix on “should” process.
   - See “12 Common Ways to Go from Is to Should.”
   - Tips:
     - Hybridize optimal process using a Pugh Matrix (see DFSS instructions).
     - Benchmark other similar processes.

Create: 12 Common Ways to Go from "Is" to "Should"

When your team reaches the improve phase and has identified (with data) the X's to improve, this can be consulted to determine what items will be needed. Steps 1-5 are less complex to implement and are often found in traditional process improvements. Steps 6-12 are increasingly more complex and suggest a need for business process redesign.

1. Eliminate unnecessary process steps
    - **Examples**: Unused data collection or reporting; one decision maker but multiple sign-offs (approval vs. information); unnecessary routing between departments; intermediaries or agents
    - **Payoffs**: Cycle time reduction; cost reduction
2. Merging and compressing process steps (may use one person instead of two or more)
    - **Examples**: Many "routed" processes; reconciling two sets of data
    - **Payoffs**: Cycle time improvement; accuracy improvement; more interesting work; cost reduction
3. Make steps parallel instead of sequential
    - **Examples**: Product development; acquisition; reviews and sign-offs; anything with multiple sequential steps
    - **Payoffs**: Reduced cycle time; faster to market
4. Use a process coordinator
    - **Examples**: Where multiple disciplines need to participate causing long cycle times; acquisitions and joint ventures; product launches; customer agreements
    - **Payoffs**: Reduced cycle time; ability to meet committed dates; reduced lost opportunities
5. Locate task where it can be done more quickly and easily
    - **Examples**: Centralized tasks that can better be done locally; plant and headquarters people working on same process; use of NetMeeting and databases
    - **Payoffs**: Reduced cycle times; better accuracy; reduced cost; better cross-functional understanding
6. Relocate work to customers
    - **Examples**: Customers enters order (online) instead of customer service; customers repair their own equipment by plugging in replaceable module; customers supply us with forecast of what they will order
    - **Payoff**: Reduced labor cost; reduced cycle time; improved accuracy
7. Relocate work from customers
    - **Examples**: Sell an assembly instead of a part; manage the customers' inventory; manage the product application for the customer; design the product or the product application process for the customer; provide customers' quality inspection
    - **Payoffs**: Business growth; better customer understanding; better planning and information; strong customer ties
8. Decrease the number of alternatives for simplicity and efficiency
    - **Examples**: Reduce number of suppliers; reduce number of distributors; reduce number of terms options
    - **Payoffs:** Less inventory; less communication; reduced cost; fewer production changeovers; less training cost; fewer errors; fewer SKU's
9. Increase the number of alternatives (pay for precision)
    - **Examples:** Serve specialty market niches; design for specific customer applications; the "customer intimacy" approach (it works only where it pays)
    - **Payoffs:** Higher margins for specialized service; custom designed products and services to reach untapped markets; close customer ties and loyalty

10. Make decisions early for efficiency
    - **Examples:** Joint demand planning with customers/distributors; production planning to reduce changeovers; advance production for seasonal sales; sales coverage planning
    - **Payoffs:** Lower production cost; lower capacity requirements; better labor efficiency
11. Make decisions as late as possible for flexibility
    - **Examples:** Hold material in jumbo or bulk - convert or package to order; ship material to West Coast - decide Asian destination later
    - **Payoffs:** Reduced inventory; better ability to respond to demand or market changes; reduced cost
12. Eliminate or reduce the impact of boundaries
    - **Boundary types:** Vertical/hierarchical; horizontal/organizational; company; political
    - **Examples:** Cross-functional and multi-level teams; mechanisms for feedback to management; joint planning with customers/distributors; joint planning with suppliers; cooperative agreements with customs agencies
    - **Payoffs**: Reduced cost internally and externally; reduced cycle time; increased goal achievement; improved communication and commitment

Validate Should Map

1. Complete “Should” FMEA to do risk analysis of improved process.
2. Validate “Should” process map with all participants (using either “structured walkthrough” or pilot study) and update as appropriate.
    - **Note:** May take several revisions to arrive at “optimum” process.

Validate: Structured Walkthrough of Should Map

1. Provide "Should" map to project team. All stakeholders and people who actually do the activities must be involved. This will check and improve the process flow, confirm who is responsible, foster buy-in, and get input from those who do the work.
2. One person role-plays each "swim lane" or function.
3. Make the walkthrough as realistic as possible:
    - Pick an actual or hypothetical scenario (do multiple scenarios to cover variation).
    - Pick a known failure from old process and validate new process is better.
    - Use props, pieces of paper, product, toy trucks, etc.
4. Follow "Should" map and record at each step:
    - How long it would take to complete
    - How many people are needed
    - Key changes from IS map
    - Start (trigger) and end points (output)
    - Measurements and information required
    - Critical skills needed
    - Key decisions made
    - Disconnects resolved
    - Identify needed sub-processes steps
    - Document performance
    - Update "Should" map as necessary
    - Do a "gut check" – ask people if this will work in "real" world situations
    - Repeat as changes are made

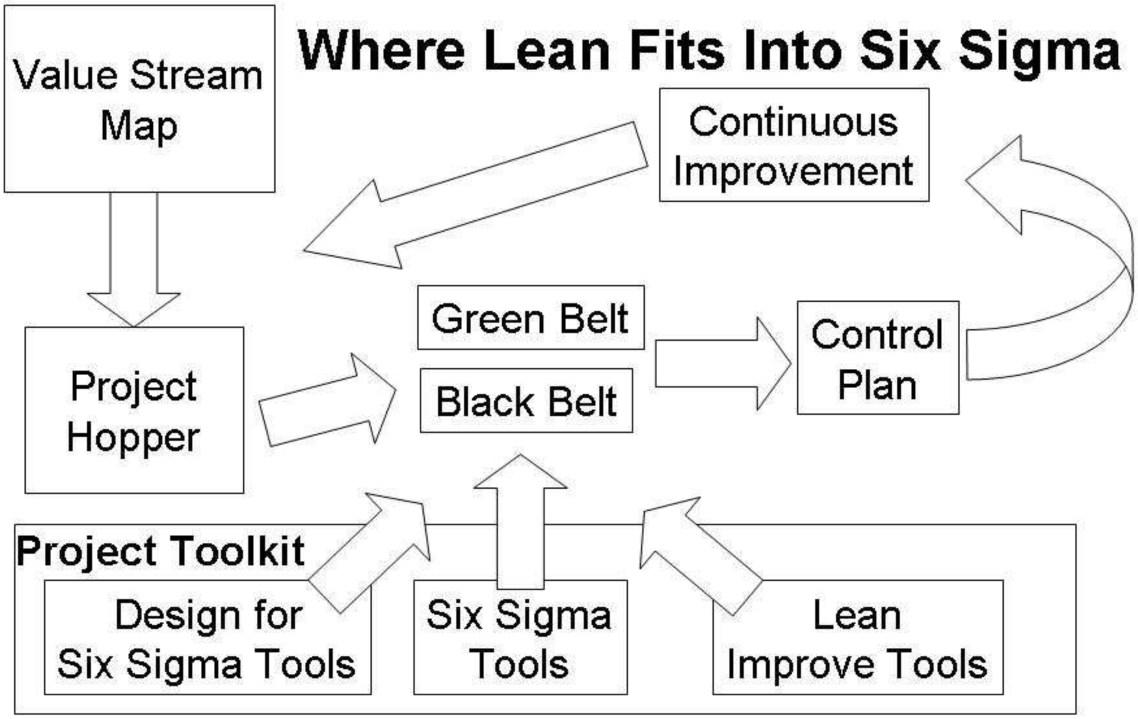
Implement Should Process

- Transition to the new process by including:
    - Communication
    - Training
    - Roles and responsibilities (RACI matrix, acceptance planning)
    - Standard Operating Procedures, test methods, etc
- Demonstrate the process works successfully and is an improvement over the original process.

D. Lean Tools

Lean is the continuous elimination of non-value added work (Muda or waste).

- Lean **primary principles**
    - **Flow** – process runs as continuously as possible with little or no inventory between process steps
    - **Pull** – Rate of each step is determined by needs of succeeding step
- The **seven wastes** that provide a framework for finding Muda:
    - **Overproduction** – producing more than is needed – the worst form of waste
    - **Unnecessary Transport** – moving material/product/information from one place to another
    - **Excess Inventory** – extra material/product/information waiting to be processed
    - **Unnecessary Motion** – excess movement and/or poor ergonomics
    - **Waiting** – idle time caused by the structure of the job or by shortages, approvals, downtime
    - **Over/Incorrect Processing** – using more steps than necessary to create a product
    - **Defects** – production of defective material, rework
- Possible **Lean tools** used during Improve phase include:
    - Value Stream Mapping
    - Just in Time
    - Standardization
    - TPM
    - Material Flow
    - SMED/Rapid Changeover
    - 5S's (Sort, Straighten, Shine, Standardize, Sustain)
    - Jidoka
    - Total Productive Maintenance
    - Kanban
    - Supermarkets
    - Production Leveling
    - Continuous Improvement
    - Takt Time Assessment
    - Poka Yoke
    - Heijunka
    - Customer Collaboration
    - Supplier Collaboration
    - Cellular Layout (Work Cells)
    - Rapid Changeover



E. Simulation

Simulation is a systems oriented, model-based analysis technique. It characterizes dynamic system behavior. Use it when actual experimentation is difficult, expensive, disruptive, and/or time consuming.

- Easily evaluate alternatives – “what-if” situations.
- Qualifies and quantifies complex systems to identify bottlenecks and constraints.
- Excellent communication tool of alternatives and decisions.
- Used for any type of process.
- Simulation models include:
  - Discrete event (time-dependent)
    - Tools: ProcessModel, Witness
    - Uses: What-if on constraints, operational and transactional processes
  - Monte Carlo (non-time dependent)
    - Tool: Crystal Ball
    - Uses: Risk analysis, new product launch

F. Pilot Study

A pilot study is a small scale implementation of a proposed solution. The intent is to verify the solution is effective before implementing it on a grand scale.

- Key issues to consider:
  - How communication will take place during and after pilot study.
  - Acceptance of risks by participants (potential negative impact).
  - Solid measurement system in place to obtain feedback (clear operational definitions and ability to analyze data identified before begin pilot study)
  - Ability to get prompt results.
  - Availability of necessary resources to conduct and evaluate pilot study.

G. Designed Experiment

There are different ways to learn about a process:

- **Passively** – Observe naturally occurring informative events (Multi-vari Studies). If you're lucky, an informative event might happen while you're watching.
- **Experimentally** – Create informative events by proactively manipulating input variables (X's) to study the effect on the output variables (Y's). Experiments, if done correctly, are efficient and powerful.

Designed Experiments

- Systematic method for using data to understand cause and effect relationships in a process.
- Changes are deliberately made to inputs (Xs) to observe changes to the outputs (Ys) following the experimental plan.
- Designed experiments take into account the inherent noise (variability) in the process.
- They study the effects of simultaneously changing more than one X and are able to detect interactions between variables.

Designed Experiment Goals

- Identify the optimal setting or configuration of the key inputs (X's) for the process (by conducting a formal experiment) and how to control those key inputs (X's).

Benefits of Designed Experiments

- Provides proof to make data-based decisions
- Efficient – maximum effort with minimum amount of time
- Cost effective
- Creates understanding and knowledge of process
- Answers questions
- Looks at multiple X's at one time
- Identifies main effects and interactions
- Simple to analyze
- Provides a mathematical model
- Identifies which X's / interactions are important or significant
- Estimates error or noise

Desirable Properties of a Designed Experiment

- Adequately covers the experimental region of interest
- Obtains the maximum information for the minimum cost of data collection
- Simple to analyze and interpret
- Enable the experimenter to:
  - Determine which factors are important
  - Develop a mathematical model
  - Test for model adequacy
  - Estimate experimental error

Common Experimental Designs

- ***Fractional Factorial*** – Used to initially investigate many X's (greater than 5) and identify which are important. (See Appendix "Analysis Roadmap – Fractional Factorial DOE")
- ***Factorial*** – Used to identify which X's are important and form limited models. Tests all combinations of the levels (number of settings) of two or more factors. All combinations of the variables are run. (See Appendix "Analysis Roadmap – Full and Fractional Factorial DOE's")
- ***Response Surface*** – Used to identify how the important X's affect the Y's and develop a model for use in optimization, process control, and determining operating windows.
- ***Mixture*** – Used in formulations to identify which X's are important and how they affect the Y's.

Two Level Factorial Experiments

Very common factorial experiment design is the two level.

- Each input (X) has two levels: low level and high level
- Two levels per input helps minimize total number of combinations
- All combinations of inputs are evaluated
- Notation used is 2^k
    - k represents number of inputs
    - 2 refers to number of levels of each input
    - 2^3 is an example of a three input design with 8 combinations ($2^3 = 2 \times 2 \times 2 = 8$ combinations)
    - $2^5 = 2 \times 2 \times 2 \times 2 \times 2 = 32$ combinations

Planning a Two Level Factorial Experiment

- **What is the experimental objective?** Will the experiment answer my questions and meet my objective?
- **What are the inputs (X's)?** Each additional input doubles the experiment.
- **What are the input (X) ranges?** Need them to:
    - Cover region of interest
    - Be wide enough to see a potential desired effect
    - Provide validation – represent day-to-day process variation
    - Provide development insight – explore beyond current window or knowledge
- **What are the outputs (Y's)?** Need to enhance understanding and aid decisions related to experimental objective. Requires an adequate test method.

Common Experimental Terms

- ***Replication*** – Number of times each **set of experimental conditions** is included in the experiment. Allows true process variability to express itself.
- ***Repetition*** – Multiple samples measured from **each experimental condition**. Provides information about short-term process variation which can be analyzed as an output if your goal is to reduce short-term variation.
- ***Randomization*** – Randomized order of gathering data. Protects against special causes during experiment.
- ***Experimental Scope*** – Area (range of inputs (X's) within which you can draw conclusions:
  - **Narrow Inference** – Experiment focused on specific subset of overall process
  - **Broad Inference** – Experiment addresses entire process (all people, all locations, all employees, etc.). Generally, more data must be taken over a longer period of time. These studies are more susceptible to noise variables.
- ***Noise Factors*** – Uncontrollable factors that increase the variability in the response. These must be managed, but it's difficult since don't necessarily know all noise factors. Use repetition, replication and randomization to minimize the effect of noise variables. Try to keep the variables constant.
- ***Blocking*** **-** Method of minimizing the effect of noise variables. Although every observation should be taken under identical experimental conditions (other than those that are being varied as part of the experiment), this is not always possible. Nuisance factors that can be classified can be eliminated using a blocked design. Assumption is that variability between blocks should be greater than the variability within blocks. Rule of Thumb: If it is a variable that you are trying to study, call it a factor. If it is a noise variable that you can't control, but know it likely will have an effect, block it.
- ***Centerpoints*** – An efficient way to test for the presence of curvature. Can not tell which factor(s) cause it. An efficient way to estimate experimental error. Centerpoint replicates can reduce the need to replicate the entire design - particularly useful for this purpose if there are 3 or more factors.

Common Designed Experiment Pitfalls

- Input levels too close together or too far apart
- Nonrandom experiments can produce spurious results
- Sample size may be too small
- Measurement systems may not be adequate
- No pilot run done: Experimental runs get screwed up because of lack of discipline
- Changing the design on the fly
- Team members insisting that standard conditions be included as points
- Extraneous sources of variation not recorded
- Data not analyzed promptly
- Data and/or experimental units lost
- Measurement system does not measure what you think it does
- Confirmation run not done to verify results

Steps to Plan a DOE

Step 1 – Define the problem in business terms (RTY, COPQ, C-P)

- Make sure that the experiment will have tangible benefits to your business objectives
- How will the results be implemented

Step 2 – State experimental objectives

- Typically "find the effects of X on Y"

Step 3 – Define the output (Y) variables (Responses)

- Is the response qualitative or quantitative?
- Is the objective to improve centering or variation?
- What is the baseline (mean and sigma)?
- Is the response in statistical control?
- How much change in the response do you want to detect?
- Is the measurement system adequate?
- Do you need multiple responses?

Step 4 – Define the input (X) variables (Factors)

- Can be controlled or uncontrolled.
- Can be from process map, C&E matrix, FMEA, Multi-vari study results, brainstorming, engineering knowledge, operator experience, scientific theory

Step 5 – Choose the factor levels

- Need to be wide enough to see a signal but not too wide to be able to see interactions
- Make sure all combinations can be sustained in production
- Dependent upon objective of experiment

Step 6 – Select experimental design

- **Screening Designs**: To isolate the "vital few" from the trivial many. Investigates a relatively large number of factors with a small number of experimental runs.
- **Characterization Designs**: To identify the key leverage variables. Investigates more complex relationships among a small number of factors (2-6).
- **Optimization Designs**: To define the optimal operating windows for key leverage variables.

Step 7 – Plan and allocate resources

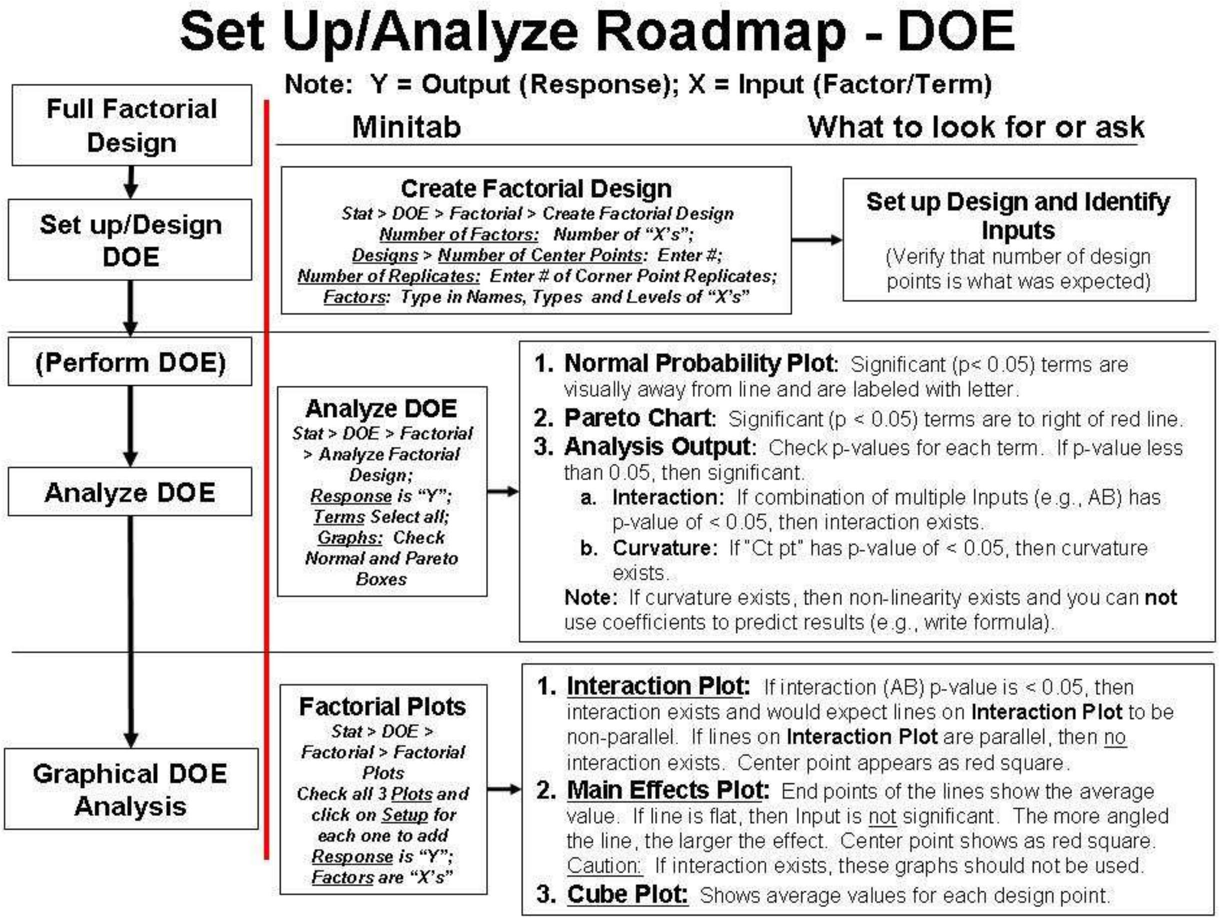
- Running an experiment cannot be done alone!
- Make sure that you have sufficient assistance from team members and others (if necessary) to: conduct a Pilot Run, stage materials, set-up process, change process settings, collect samples, ecord data, input data, analyze data.

Step 8 – Generate and review proposal

- Experimental proposals are essential and must be circulated for acceptance / input. Not all successful experiments have results that are implemented.
- You need support and understanding from the process owners to effectively implement changes from your findings!
- Inputs from others on input level selection can same time, money, and prevent safety issues. Make sure that the proposal is reviewed by personnel that have experience and 'tribal knowledge' for a sanity check.

Typical DOE Setup/Analyze

The following roadmap can be used to setup/analyze a DOE. Get assistance from your Black Belt or coach before setting up a DOE!



Set Up/Analyze Roadmap - DOE

Note: Y = Output (Response); X = Input (Factor/Term)

Create Factorial Design
Stat > DOE > Factorial > Create Factorial Design
Number of Factors: Number of "X's";
Designs > Number of Center Points: Enter #;
Number of Replicates: Enter # of Corner Point Replicates;
Factors: Type in Names, Types and Levels of "X's"

Set up Design and Identify Inputs
(Verify that number of design points is what was expected)

Analyze DOE
Stat > DOE > Factorial > Analyze Factorial Design;
Response is "Y";
Terms Select all;
Graphs: Check Normal and Pareto Boxes

1. **Normal Probability Plot**: Significant (p< 0.05) terms are visually away from line and are labeled with letter.
2. **Pareto Chart**: Significant (p < 0.05) terms are to right of red line.
3. **Analysis Output**: Check p-values for each term. If p-value less than 0.05, then significant.
   a. **Interaction:** If combination of multiple Inputs (e.g., AB) has p-value of < 0.05, then interaction exists.
   b. **Curvature:** If "Ct pt" has p-value of < 0.05, then curvature exists.

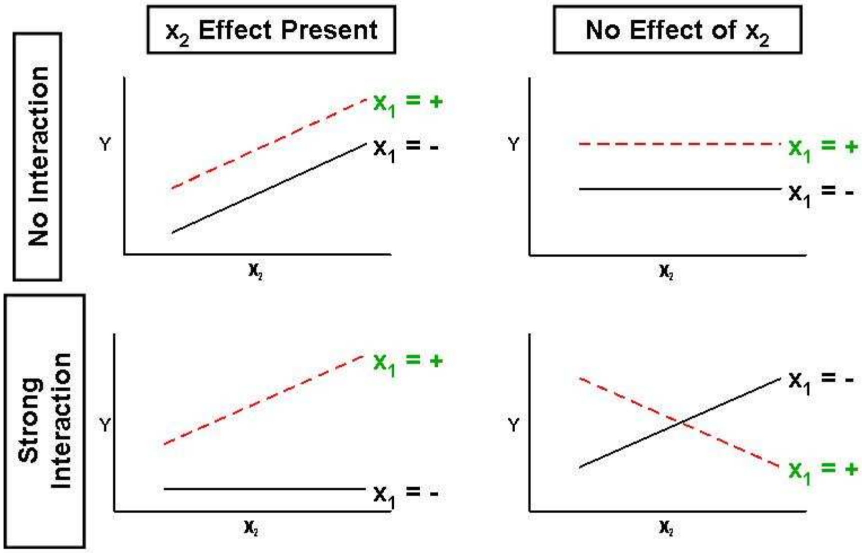
Note: If curvature exists, then non-linearity exists and you can **not** use coefficients to predict results (e.g., write formula).

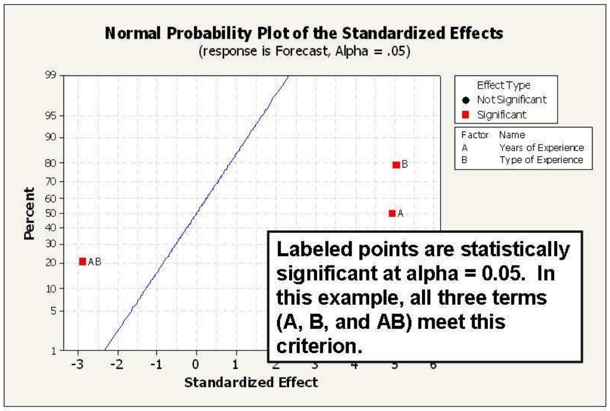
Factorial Plots
Stat > DOE > Factorial > Factorial Plots
Check all 3 Plots and click on Setup for each one to add Response is "Y"; Factors are "X's"

1. **Interaction Plot:** If interaction (AB) p-value is < 0.05, then interaction exists and would expect lines on **Interaction Plot** to be non-parallel. If lines on **Interaction Plot** are parallel, then no interaction exists. Center point appears as red square.
2. **Main Effects Plot:** End points of the lines show the average value. If line is flat, then Input is not significant. The more angled the line, the larger the effect. Center point shows as red square. Caution: If interaction exists, these graphs should not be used.
3. **Cube Plot:** Shows average values for each design point.

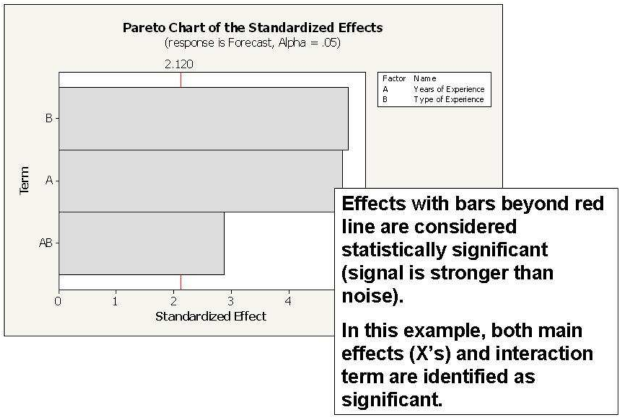
DOE Analysis: Factor Significance

- Effect of each input (X) represents a potential signal in the data.
- Given an estimate of noise in system, a signal/noise (S/N) ratio may be formed for each Effect to judge whether or not the input (X) is significant. Does effect stand out from noise?
- Minitab lists a p-value for each input (X) and interaction. Inputs (X's) with a p-value < 0.05 indicate a significant S/N ratio (a significant input (X) that results in a change in Y)



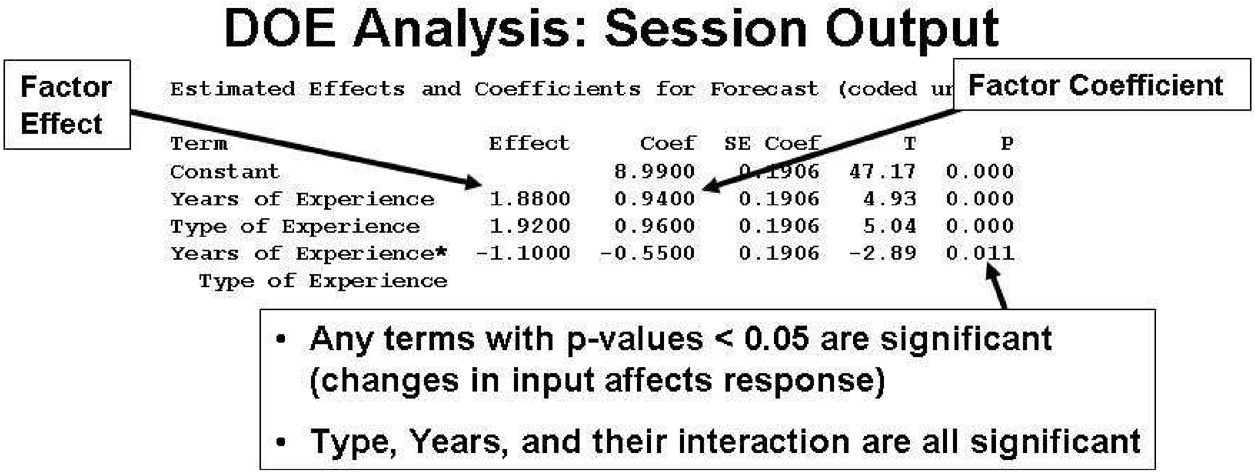


Labeled points are statistically significant at alpha = 0.05. In this example, all three terms (A, B, and AB) meet this criterion.



Effects with bars beyond red line are considered statistically significant (signal is stronger than noise).

In this example, both main effects (X's) and interaction term are identified as significant.



DOE Analysis: Session Output

Factor Effect

Factor Coefficient

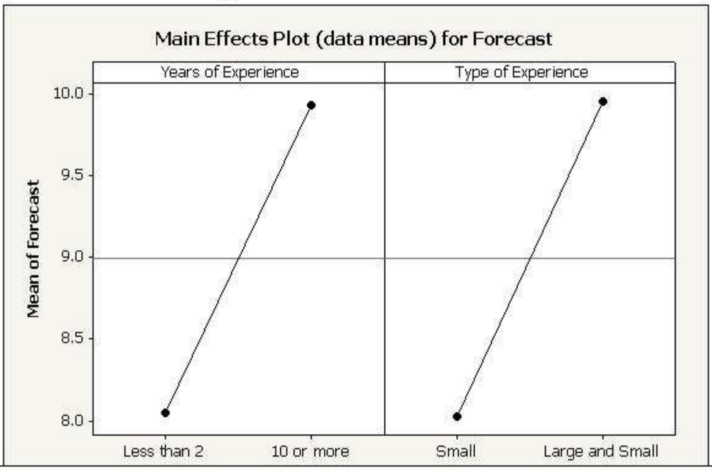
```
Estimated Effects and Coefficients for Forecast (coded ur

Term                         Effect     Coef  SE Coef      T      P
Constant                               8.9900   0.1906  47.17  0.000
Years of Experience          1.8800    0.9400   0.1906   4.93  0.000
Type of Experience           1.9200    0.9600   0.1906   5.04  0.000
Years of Experience*        -1.1000   -0.5500   0.1906  -2.89  0.011
  Type of Experience
```

- Any terms with p-values < 0.05 are significant (changes in input affects response)
- Type, Years, and their interaction are all significant

DOE Analysis: Factorial Plots

- Effect plots graphically depict how each input (X) affects the response.
- **Main Effect Plot** – Plots averages at each level of an input (X). A straight line connects the two averages.
- **Interaction Plot** – Plots averages at each level of an input (X) with the level of a second input held constant.
- **Cube Plot** – Plots cube (or square) showing averages of all points at the given combination of input (X) levels.

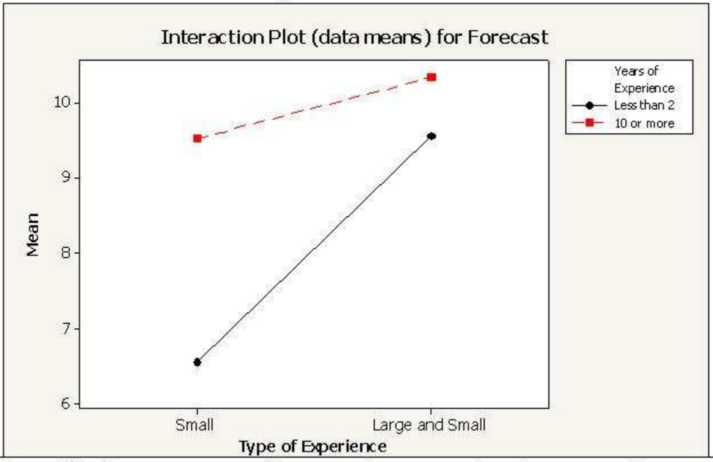
DOE Analysis: Main Effect Plots



Years and Type of experience have about the same effect, since their slopes are the same. Horizontal line represents overall average of data and serves as a reference line.

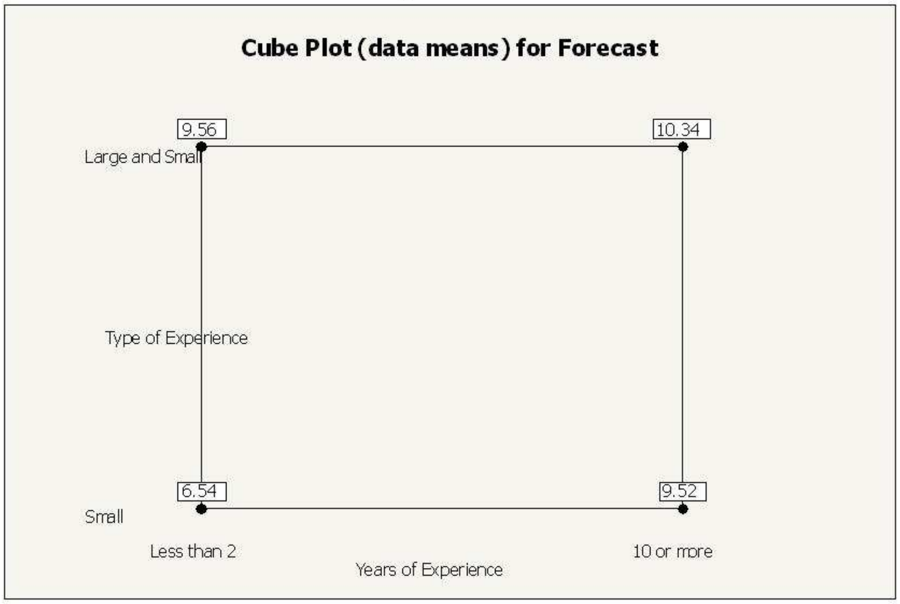
Note: If there is an interaction, this plot should not be used.

DOE Analysis: Interaction Plot



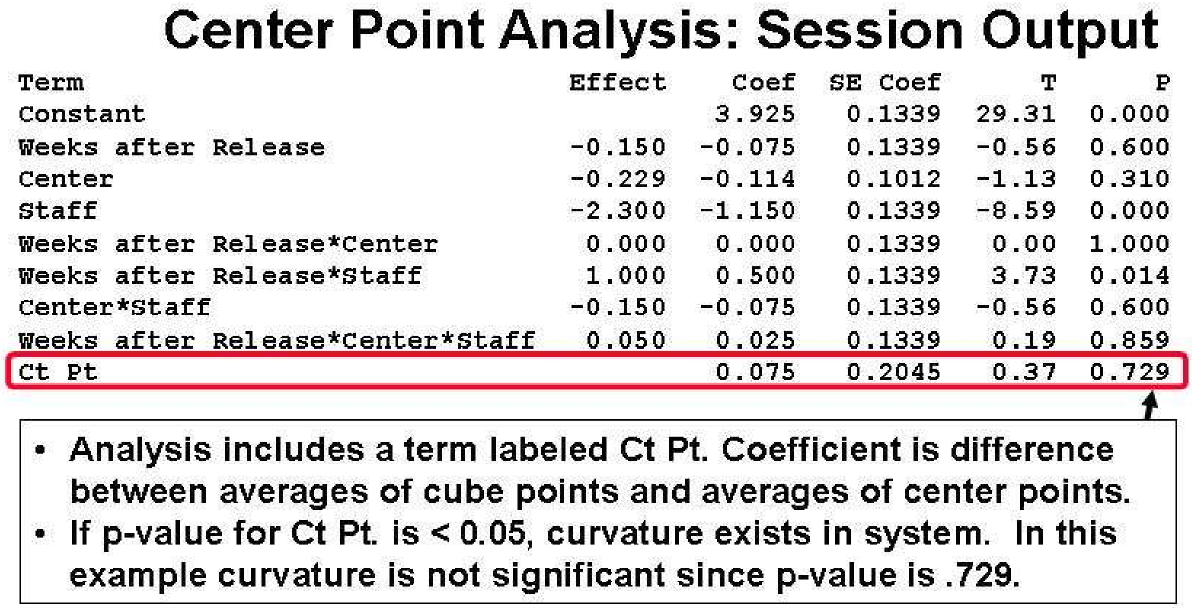
- **People with few years of experience who have only worked on small projects tend to forecast lower costs.**
- **If someone has more than 10 years of experience, type of projects doesn't matter much.**
- **If someone has worked on large and small projects, number of years has little effect.**

DOE Analysis: Cube Plot



DOE Analysis: Checking Model Validity with Centerpoints

- The DOE model assumes a linear response curve. If the output (Y) increases along a curve versus the input (X), a mathematical model is only valid for the endpoints. To get a predictive model a 2nd order design needs to be run. If this possibility was considered in advance the "star points" can be added and the original design also utilized. (See your Black Belt or coach for assistance.)
- The null hypothesis (H_o) is the line does not have a curve (it is straight).



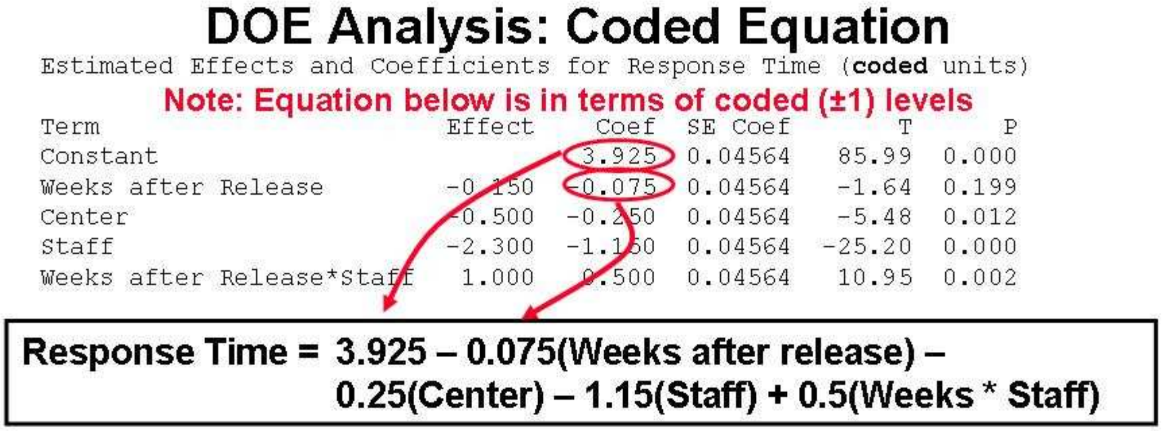
Center Point Analysis: Session Output

```
Term                               Effect     Coef  SE Coef       T      P
Constant                                     3.925   0.1339   29.31  0.000
Weeks after Release                -0.150   -0.075   0.1339   -0.56  0.600
Center                             -0.229   -0.114   0.1012   -1.13  0.310
Staff                              -2.300   -1.150   0.1339   -8.59  0.000
Weeks after Release*Center          0.000    0.000   0.1339    0.00  1.000
Weeks after Release*Staff           1.000    0.500   0.1339    3.73  0.014
Center*Staff                       -0.150   -0.075   0.1339   -0.56  0.600
Weeks after Release*Center*Staff    0.050    0.025   0.1339    0.19  0.859
Ct Pt                                        0.075   0.2045    0.37  0.729
```

- Analysis includes a term labeled Ct Pt. Coefficient is difference between averages of cube points and averages of center points.
- If p-value for Ct Pt. is < 0.05, curvature exists in system. In this example curvature is not significant since p-value is .729.

DOE Analysis: Equations

- The DOE model provides coefficients that can be used to write a predictive equation for within the experimental range. **Warning:** If Center Point is significant, there is non-linearity and this equation can not be used to predict.



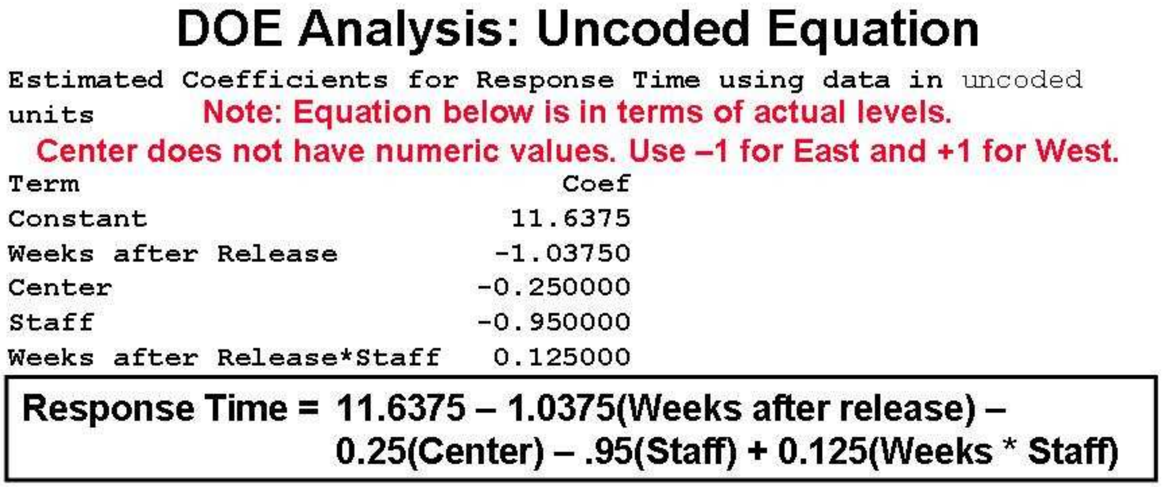
DOE Analysis: Coded Equation

```
Estimated Effects and Coefficients for Response Time (coded units)
```

Note: Equation below is in terms of coded (±1) levels

```
Term                         Effect      Coef   SE Coef        T       P
Constant                                3.925   0.04564    85.99   0.000
Weeks after Release          -0.150    -0.075   0.04564    -1.64   0.199
Center                       -0.500    -0.250   0.04564    -5.48   0.012
Staff                        -2.300    -1.150   0.04564   -25.20   0.000
Weeks after Release*Staff     1.000     0.500   0.04564    10.95   0.002
```

Response Time = 3.925 – 0.075(Weeks after release) – 0.25(Center) – 1.15(Staff) + 0.5(Weeks * Staff)



DOE Analysis: Uncoded Equation

```
Estimated Coefficients for Response Time using data in uncoded
units
```

Note: Equation below is in terms of actual levels.

Center does not have numeric values. Use –1 for East and +1 for West.

```
Term                              Coef
Constant                       11.6375
Weeks after Release           -1.03750
Center                       -0.250000
Staff                        -0.950000
Weeks after Release*Staff     0.125000
```

Response Time = 11.6375 – 1.0375(Weeks after release) – 0.25(Center) – .95(Staff) + 0.125(Weeks * Staff)

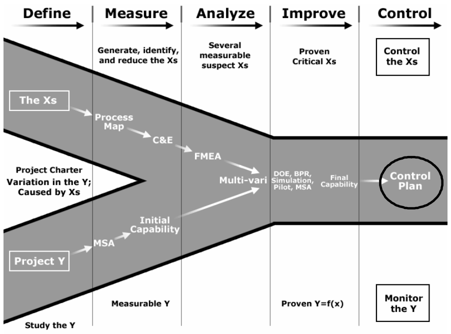
Improve Phase Checklist

☐ Did you identify and validate critical X's?
☐ Did you verify $\boxed{y = f(x_1, x_2, ..., x_k)}$?
☐ Was a process improvement plan identified?
☐ Was a new process baseline created?
☐ Did you get improvement needed?
☐ Do you need to do a verification run or pilot?
☐ Do you need to develop a training plan and conduct training?
☐ What documentation is needed? (Operating procedures, training documentation, test methods, cross-functional map)
☐ What change acceptance tools are needed? Stakeholder analysis, RACI, WIIFM, etc
☐ What is your measurement system?
☐ What is your communication plan?
☐ Do you have everything you need to sustain improvement?
☐ Did you address all the risks?
☐ Are we ready to implement the improvement?

Lessons Learned

VI. Control

The Roadmap



Control Phase Purpose:

- Establish control plan to ensure the process consistently meets the customer requirements.
- Implement changes to maintain the gains achieved by the project.
- Meet customer requirements all the time.
- Control the critical inputs (X's) – achieve the outputs (Y's).

Control Phase Goals:

- Improve and sustain performance with well executed control plans.
- Implement changes to meet project requirements.
- Control critical inputs (Xs) to achieve desired outputs (Ys).
- Process owner and champion accept and drive changes and utilize control plan.
- GPS and PDR are updated.
- Project is completed and financials are tracked

A. Control Plan

A control plan is the documents that provide "One-stop shopping" for all relevant project information.

What should be in a Control Plan?

a. **Control plan summary** (see ubertool): Excel spreadsheet that summarizes all key inputs, outputs, control mechanisms, specifications, measurement techniques, responsible parties. Place to document all relevant inputs (X) and output (Y) information. Summary should include:
   - Critical Xs and Ys to monitor
   - Responsible people
   - Measurement system
   - Links to process documentation (training, SOPs, etc)
   - Reaction plan
   - Audit plan
   - Review templates for ideas on components appropriate to your projects

b. **"Dashboard"**: One sheet for quick understanding and response regarding process performance, much like the dashboard gages for the driver in a car. Communicates process performance through up-to-date control charts for process Y and critical X's, and any other pertinent process information. Also used to show ongoing capability.

c. **Systems & Structures:**

- Control by documentation of process roles like RACI matrix (graphical task documentation)
- Control by standardization (common criteria used by all process participants)
- Mistake proofing methods (eliminate mistakes before they occur)
- Training methods and material (more than training – includes knowledge transfer):
  - WHY process needs to be run this way
  - HOW affects customers if it isn't run this way
  - WHAT it affects from product or service performance, reliability, safety, and financial perspectives
  - WHO can assist with problems
  - WHAT their responsibility is
  - HOW they can make improvements to process
  - **Hint:** Consider pre-test and post-test to check for effectiveness of training
  - **Training Pitfalls:**
    - Training plan not updated to match process improvements
    - Unqualified people conduct the training
    - "Pyramid scheme" training: Current employee assigned to process trains next person. Second person trains the third person. Critical process understanding is lost and processes go out of control, no one knows why. End up conducting another Six Sigma project to bring the process under control again.
- Rewards and recognition

d. **Process Documentation:**

- Documentation should include: how task is performed; when or how frequently it is performed; who needs to use and maintain documentation; what information is used to make decisions; and what needs to be measured and recorded.
- Included in the documentation are: Standard Operating Procedures (SOPs), work instructions, records, measurement tools/methods, customer specifications, process output, training materials, reaction plans, etc.
- A process checklist can be used to assure a sequence of tasks/steps are completed are critical to process integrity.
  - Examples: startup and process set point monitoring checklists; order entry checklist; promotional activity checklist; hiring checklist; shutdown checklist; periodic process variable checklist.
  - Not a foolproof method. Possible that checklists can be completed without performing or observing process (require a sign off to help with this).
  - Helpful on transactional processes where observations or statistical process control are difficult to do.

e. **Acceptance Strategies:** Some process improvements are going to result in pushback. Good deployment plans will have considered and used available acceptance strategies. These include: Force Field Analysis (Enablers/Restrainers), Stakeholder Analysis, WIIFM (What's in it for me?).

f. **Friendly Audit Plan**: Periodic examination of records/process ensure people are using the new procedures, that they are clear and understandable, and to check for necessary updates. Set up a plan and schedule a "friendly audit" with an independent auditor.

- Observe the procedure
    - Are people actually doing what procedure says?
    - Are all steps being followed?
    - Are people referring to procedure?
- Ask questions about the process
    - Is each step in procedure clear?
    - How could we improve procedure and still get results?
    - Are you using your reaction plan?
- Conduct indirect observation
    - How old are the procedures?
    - Are they being updated?
    - Are they being used?

Control Plans – Common Pitfalls

- Not involving affected employees in creating the procedures or not communicating background to them.
- Not testing procedures before global implementation.
- Incomplete information in procedures: can't produce correct value of Y measurement controlling Xs with this plan; incomplete reaction plan, corrective action won't fix problem.
- Not having a reaction plan.
- Lowering importance of procedures – either by not updating them or by management not actively enforcing them.
- Putting procedures on shelf and not implementing them.

Control Plans – Hints

- Involve your process owner and full team in developing the control plan to ensure agreement.
- Be sure to include training as part of your control plan to ensure people know how to use the new process.
- Keep it simple.
- Make it visual.
- Keep it up-to-date/current.

Steps to Create a Control Plan

1. Collect all process and project documentation
2. Prepare initial draft of control plan
3. Update all SPC charts and capability studies
4. Prepare dashboards (with instructions of how they are to be prepared)
5. Identify missing or inadequate components — gaps
6. Prepare reaction plan
7. Secure sign-offs from safety & environmental, maintenance, operations and process engineering
8. Verify compliance with company documentation requirements
9. Train affected personnel
10. Conduct hand off meeting(s)

Next Steps

- Conduct process owner hand-off training
- Document final capability
- Obtain sign-off from Process Owner and Champion
- Put all documentation in GPS and PDR
- Discuss replication opportunities discussed
- Do final close presentation (see BB before close)

Lessons Learned

Control Phase – Completion Checklist

☐ Process that is in control and capable of meeting customer requirements
☐ Control plan with measurement plan
☐ Deployment plan including: plan for systems and structures, change management plan
☐ Shared best practices
☐ Financial gains tracked
☐ Discuss what next steps will be on bridge to entitlement
☐ If you have a question, ASK!

Appendix 1 – Key Terms

α Risk – Taking action when you didn't need to. The probability of rejecting H_o when it is true (Type I error) is equal to α.

Acceptance Strategy – A collection of methods and tools utilized to ensure that changes affecting people are successful.

Accuracy – How close is your measurement system to getting the true answer.

Affinity Diagrams (AD) – A technique used for gathering large amounts of language data and organizing it into natural groupings. Typically used to help define processes that are not completely clear.

Alias – describes the confounding that occurs in a designed experiment.

Alternative Hypothesis, H_a – The statement of change or difference. This statement is considered true if H_0 is rejected.

Analyze – A phase in the Six Sigma DMAIC process that focuses on analyzing with data the relationships between X's and Y's to identify the possible sources of variability.

Attribute MSA – A type of Measurement Systems Analysis used to evaluate the performance of qualitative assessments.

β Risk – Not taking action when you should have. β is the risk of retaining H_o when it is actually false (Type II error).

Baseline – The level of performance of the process when the project begins. It is used in determining what kind of impact process improvements have when implemented as well as their financial impact. How good is a process today.

Best Practice – A method or solution identified as one that produces breakthrough results and could be used on other projects.

Bias – Describes the difference from observed value to true value. It can be explained as the difference between the average of all repeated measurements that might be made on a sample at a given time, and its true value.

Black Belt (BB) – A process improvement project team leader who is trained in the DMAIC methodology and tools, and who is responsible for project execution.

Boiling the Ocean – A project that is scoped too large.

BP Chart – An Excel based software package that creates control charts of time ordered data. Its major advantage is its ability to incorporate trends or seasonality in a data set.

Breakthrough Goal – A dramatic, near immediate and significant improvement. In measurement terms, reaching a breakthrough goal represents an improvement of 60 to 80 percent of the way to entitlement.

Business Critical Y (BCY) – Key high-level business goals and/or measures. Used to focus and align Six Sigma projects to business unit strategic direction. An important part of a Goal Tree.

Business Process Redesign – Also known as "business process improvement," "business process reengineering," and "business process design." The use of cross-functional IS and Should maps to understand, and improve or redesign a business process (transactional and operational processes) to achieve business results.

Calibration Standard – Known measure used to calibrate measurement equipment, often traceable to a national standard.

Capability – The total range of inherent variation in a stable process. It is generally determined by comparing the process variation to the customer specifications and/or by using data from control charts.

Capability Index – A calculated value used to compare process variation to a specification. Examples are C_p, C_{pk}, P_p, and P_{pk}. Can also be used to compare processes to each other.

Cause & Effects (C&E) Matrix – A simplified QFD (Quality Function Deployment) matrix to emphasize the importance of understanding customer requirements. It relates the key inputs (X's) to the key outputs (Y's) using the Process Map as the primary source. The key outputs are scored for their importance to the project. The key inputs are scored based on their relationship to the key outputs.

Champion – An upper level business leader who facilitates the leadership, implementation, and deployment of the process quality initiative and breakthrough philosophies. Responsible for removing roadblocks and assuring adequate resources for a Six Sigma project.

Close – A project status where all the DMAIC steps have been completed (including final capability). Financial tracking is ready to start or is in progress.

Coefficient of Determination – R^2, the proportion of variation in the response data that is explained by the regression model. R^2 is calculated as 1 minus the ratio of the error sum of squares over the total sum of squares. It is one of the criteria used to check whether the regression model fits the data well.

Common Cause Variation – The inherent variation in a process. It is always part of the process and cannot be removed except through major process modification.

Confounded – A When you have a fractional design, some of the effects are confounded with each other. That is, you cannot estimate all the effects separately. For example, if Factor A is confounded with the three-way interaction BCD, then the estimated effect for A also includes any effect due to the BCD interaction. Effects that are confounded are said to be aliased.

Continuous Variable – A variable that can take on many different values. It will always be in numeric form. Some examples are time, temperature, weight.

Control – A phase in the Six Sigma DMAIC process that focuses on maintaining the improved process to achieve the financial results.

Control Chart – A plot of data over time. The plot includes a central line and limits that reflect the natural variation in the process. If all plotted points are within the control limits, the process is considered to be within statistical control.

Control Limits – Upper and/or lower bounds on a control chart used to detect special causes. They are based on the variability of the process and generally calculated as +/- 3 sigma. Points outside the limits are interpreted as a signal that the process has changed in some way.

Control Plan – A written description of the system to control parts and processes; a detailed assessment and guide for maintaining all positive changes made by the project team.

Controlled Inputs – Inputs that can be changed to see the effect on outputs.

Cost of Poor Quality (COPQ) – Cost associated with poor quality products or services. Examples: Product inspection, Sorting, Scrap, Rework, and Field Complaints.

Correlation – The strength of the linear relationship between two continuous variables

C_p - Capability index - The ratio of the Voice of the Customer to the Voice of the Process. Indicates how capable the process is of meeting customer expectations. Relates the process spread (the 6σ variation) to the specification spread. In other words, C_p relates how the process is performing to how it should be performing. C_p does not consider the location of the process mean relative to the specification interval. C_p tells you what capability your process could achieve if centered.

C_{pk} - Capability index - Like the C_p, indicates how capable the process is of meeting customer expectations. Will be lower than the C_p if the process is not centered between the specification limits. Minimum of C_{pU} and C_{pL}. C_{pk} incorporates information about both the process spread and the process mean, so it is a measure of how the process is actually performing. Note that C_{pk} considers the location of the process mean, while C_p does not. If C_p and C_{pk} are approximately equal, then the process is centered between the specification limits. If C_p is greater than C_{pk}, then the process is not centered.

C_{pm} - Capability index - Provided only when you specify a target. C_{pm} examines the process spread and the shift of the process mean from the target and compares them to the specification spread. C_{pm} does not use the within-subgroup standard deviation.

C_{pL} - Capability index - Relates the process spread (the 3σ variation) to a single-sided specification spread (μ-LSL). C_{pL} considers both process mean and process spread. Use C_{pL} when you have a single-sided lower specification limit to compare to.

C_{pU} - Capability index - Relates the process spread (the 3σ variation) to a single-sided specification spread (USL-μ). C_{pU} considers both process mean and process spread. Use C_{pU} when you have a single-sided upper specification limit to compare to.

Corporate Y – High-level goal at the top of the goal tree. 3M corporate Y’s are Growth, Cost, and Cash. All Six Sigma projects relate to one or more of the corporate Y’s.

Counterbalance Y – A metric used as a checking metric. Improvements in the Project Y should not have a negative impact on the counterbalance Y.

Critical to Quality (CTQ) – Elements of a process that significantly affect the output of that process. Identifying these elements is vital to figuring out how to make the improvements that can dramatically reduce costs and enhance quality.

Critical Inputs – Inputs that have been statistically shown to have a major impact on the variability of outputs.

Critical X – Those few process input variables that a Six Sigma project focuses on. By adjusting the critical X’s, the process performance can realize a major improvement.

Defect – Any characteristic that deviates outside of specification limits or customer requirements.

Defects per Million Opportunities (DPMO) – A measure of attribute process capability that can be used to compare processes with different levels of complexity. Calculated by dividing the DPU by the number of opportunities for a defect to occur.

Defects per Unit (DPU) – A measure of attribute process capability that divides the total number of defects by the number of units.

Define – Define phase of Six Sigma process (DMAIC) defines the problem/opportunity, process, and customer requirements. The Define phase includes setting project goals and boundaries based on knowledge of the organization's business goals, customer needs and the process that needs to be improved to reach a higher Six Sigma level.

Design for Six Sigma (DFSS) – The application of Six Sigma tools to product development and Process Design efforts with the goal of "designing in" Six Sigma performance capability.

Design (Layout) – Complete specification of experimental conditions including blocking, randomization, replications, repetitions, and assignment of factor-level combinations to experimental units.

Design FMEA – An analytical technique used by a design responsible engineer/team as a means to assure, to the extent possible, that potential failure modes and their associated causes/mechanisms have been considered and addressed.

Design for Manufacturability (DFM) – A simultaneous engineering process designed to optimize the relationship between design function, manufacturability, and ease of assembly.

Design of Experiments (DOE) – An efficient method of experimentation, which identifies, with minimum testing, factors (key process input variables) and their optimum settings that affect the mean and variation.

Design Validation – Testing to ensure that product conforms to defined user needs and/or requirements. Design validation follows successful design verification and is normally performed on the final product under defined operating conditions. Multiple validations may be performed.

Design Verification – Testing to ensure that all design outputs meet design input requirements.

Destructive Test – When the test method used destroys the sample.

Discrete Variable – A variable that can only take a finite number of values. It can be a "verbal" description or attributes. E.g. Defect category, Machine type, number of safety incidents.

DMAIC – Acronym for Define, Measure, Analyze, Improve, Control. The 5 phases of the Six Sigma methodology used to make process improvements.

Effect – The change in the average response over two levels of a factor or between experimental conditions.

Empirical Rules – Approximate guidelines for the amount of data that will fall within certain values of the mean. 60-75% will fall within 1 standard deviation of the mean, 90-98% within 2 standard deviations, and 99-100% within 3 standard deviations.

Entitlement – The full potential benefit we can achieve from a process. Six Sigma projects consider entitlement as "what's the best we can get from a process" to help them in setting process improvement goals. Best state to date of a process. Generally comes from observed results, benchmarking, or theoretical calculations.

Entitlement Quality (EQ) – {Formerly known as Cost of Poor Quality (COPQ)} - Cost associated with poor-quality products or services. Examples: costs associated with product inspection, sorting, scrap, rework and field complaints.

EVOP – Evolutionary Operations - continuous on-line process improvement by using DOE's.

Experimental Region (Factor Space) – All possible factor-level combinations for which experimentation is possible.

Experimental Run – A single combination of factor levels that yields one or more observations of the output variable.

Factorial Designed Experiment – In a full factorial experiment, responses are measured at all combinations of the experimental factor levels. Each combination of factor levels represents the conditions at which a response measure will be taken.

Factors – A factor is one of the controlled or uncontrolled variables being studied in the experiment

Factor Levels – The levels of a factor are the values being examined in the experiment.

Feasibility – A determination that a process, design, procedure, or plan can be successfully accomplished in the required time frame.

First Pass Yield (FPY) – The percentage of products or services that are successfully completed on the first attempt without requiring remedial action or rework.

Final Capability – The performance level of the improved process. Data is required to show that the process has reached this level in order to close a project.

Fishbone Diagram – Sometimes called a Cause and Effects Diagram or Ishikawa Diagram. A graphical method of representing the relationships between effects and their causes. Causes are generally grouped into categories such as Machine, Method, or People.

FMEA - Failure Modes and Effects Analysis – A tool for linking failure modes to cause & effect so that process controls to reduce the occurrence of producing unacceptable product can be implemented or detection methods can be improved. Prioritizes improvement.

Fractional Factorial Designed Experiment – Fractional factorial designs are useful in factor screening as they reduce the number of runs to a manageable size. The runs that are performed are a selected subset or fraction of the full factorial design. When you do not run all factor level combinations, some of the effects will be confounded. Confounded effects cannot be estimated separately and are said to be aliased.

Gage Bias (also known as Accuracy) – The difference between the true or reference value and the observed average of multiple measurements of the identical characteristic on the same part.

Gage R&R – A type of Measurement Systems Analysis used to evaluate test methods. It is generally used with continuous data and can be used to quantify the total variability as well as the Repeatability and Reproducibility of a measurement system.

Gage Repeatability – The variation in measurements obtained with one measurement instrument when used several times by one appraiser while measuring the identical characteristic on the same part.

Gage Reproducibility – The variation in the average of the measurements made by different appraisers using the same measuring instrument when measuring the identical characteristic on the same part.

Gap – The difference between entitlement and baseline.

Goal – The target amount of improvement for a process.

Goal Tree – Diagram showing linkage of Corporate Critical Y's, Business Critical Y's, and Projects.

Green Belt (GB) – A person who is trained in the DMAIC methodology and tools, and who may lead project teams or assist on a phase of a larger project.

Histogram – A graphical way of summarizing data by plotting possible values on one axis and the observed frequencies for those values on the other axis. It helps one visualize the central tendency and dispersion of the data.

Hopper – A collection of identified Six Sigma projects that have not yet started.

Hypothesis Testing – A way of analyzing data, particularly from DOEs, that tries to determine if results observed are statistically significant; in particular, are the results possibly due to random variation?

I & MR – Individuals and Moving Range chart; a type of variables control chart based on individual measurements.

Interaction – The combined effect of two factors that is over and above the singular effect of each factor.

Internal Reference Material (IRM) – a sample that can be measured repeatedly to "calibrate" test method or insure no change in test method.

Interrelationship Digraph (ID) – A technique used to map out logical or sequential links among ideas, issues, or problems. Can be used to determine key drivers and outcomes of a process.

Improve – A phase in the Six Sigma process that focuses on quantifying and proving the relationship between the X's and the Y and then changing the X's to improve the Y.

IS Map – A cross-functional process map completed during the Measure phase. A view of the current or existing process that shows who does the work and in what relative timeframe.

Key Process Input Variable (KPIV) – The vital few process input variables that have the greatest effect on the output variable(s) of interest. They are called "X's", (normally 2 to 6).

Key Process Output Variable (KPOV) – The output variable(s) of interest. They are called the "Y's", (usually 1). May be process performance measures or product characteristics.

Levels – Refers to the number of settings of a particular factor

Main Effect – The Average change from one level to another for a single Factor

Master Black Belt (MBB) – A person who is trained in DMAIC methodology and project definition / implementation. Master Black Belts play a key role in coaching Black Belts.

Mean, μ – Greek letter denoting the arithmetic average of a set of values.

Measure – A phase in the Six Sigma process that focuses on defining the current process. In addition, it establishes initial performance levels and determines our ability to measure the process.

Measurement System – The complete process used to obtain measurements. It consists of the collection of operations, procedures, gages and other equipment, software, and personnel used to assign a number or value to the characteristic being measured.

Measurement System Analysis (MSA) – Use of statistical methods to evaluate the performance of a measurement system. The three major types are Data audits, Attribute MSA, and Gage R&R.

Measurement – Test values obtained by performing the complete test procedure including sample preparation as well as reading.

Measurement System – The complete process used to obtain measurements. It consists of the collection of operations, procedures, gages and other equipment, software, and personnel used to assign a number or value to the characteristic being measured.

Median – The center number of a data set after it has been rank ordered. Equivalent to the 50th percentile.

Minimum Difference (δ) – The minimum difference (δ) from the hypothesized value we want to detect with power 1- β

MINITAB™ – The main statistical software package used by the Black Belts and Green Belts.

Multi-Vari Chart – A graphical way of depicting variation within a single part, machine or process, or between parts (produced at the same time or over time). Allows the study of process inputs and outputs in a passive mode (natural day-to-day process).

Multi-Vari Study – A graphical and statistical method to depict variation in the KPOV as it relates to changes in multiple KPIVs. Variables include noise variables potentially causing variability in the process. The study of process inputs and outputs is completed in a passive data collection mode.

Noise – The inherent variability in the system.

Normal Distribution – A continuous, symmetrical, bell shaped frequency distribution for variable data.

Null Hypothesis, H_0 – The statement of no change or difference. This statement is assumed true until sufficient evidence is presented to reject it.

Operational Definition – The definition created by the team that relates to a term used or process practiced within the team framework.

Outlier – A data point that is markedly different from the others. Many times it is the result of a special cause or exception in the process.

p-value – Probability that the observed results could occur when H_0 is true.

Population – The universe of all possible numbers that can be considered the same in some sense.

Precision – The standard deviations of repeated measurements at identical conditions

Probability - The chance of an event happening or a condition occurring in a random trial.

Process – The combination of people, equipment, materials, methods, and environment that produce a given product or service. It is the particular way of doing something.

Process Map – A step-by-step pictorial sequence of a process showing process inputs, process outputs, cycle time rework operations, and inspection points.

Process Owner – Person responsible to follow and utilize the control plan to ensure that the process maintains its improved state.

Process Spread – The extent to which the distribution of individual values of the process characteristic (input or output variable) vary; often shown as the process average plus and minus some number of standard deviations. Other related measures of spread include the range or quartiles.

Project Charter – A document containing the key information about a Six Sigma project. Includes the business justification, process to be improved, team members, project description and metrics, and financial information.

Project Scope – The specific process(es) or part of the process that the project is focusing on. It is essentially the project boundaries.

Project Y – A measurable, key process output used to determine improvement of the process. The aim of the project is to improve the Project Y.

QFD – Quality Function Deployment; a process that links customer requirements to product/process characteristics to manufacturing procedures so that our products satisfy our customers and are produced with processes that have high C_{pk} ratios.

Qualitative Information – Expressed in “verbal” terms and descriptions. Information is gathered by counting frequency of occurrences. Also described as discrete.

Quantitative Information – Expressed in numerical form. Numeric information can be discrete or continuous.

$R, \overline{R}$ – Range and average range. Used in SPC to determine state of control and process limits.

R^2 – Coefficient of Determination – The proportion of variability explained by a regression model.

RACI matrix – Responsible, Accountable, Consultant, Informed – A standard X vs. Y matrix that relates specific tasks to individuals and/or functional roles. Can help to identify gaps or conflicts about who is involved in a process and what they do.

Randomization – Experimental runs are performed in a randomized order to eliminate the effect of variables not being studied.

Readings – Test values obtained by presenting a prepared sample to the test equipment more than once without redoing sample preparation in between.

Regression analysis – A statistical technique used to investigate and model the relationship between variables.

Response Surface Designed Experiment – Response surface methods are used to examine the relationship between one or more response variables and a set of quantitative experimental variables or factors. These methods are often employed after you have identified a "vital few" controllable factors and you want to find the factor settings that optimize the response. Designs of this type are usually chosen when you suspect curvature in the response surface.

Resolution – The smallest unit of measure that you have. It can also be defined as the number of decimal places that can be measured by the system. Increments of measure should be about one-tenth of the width of the product specification or process variation.

Repeatability – The inherent variability of the measurement system. When repeated measurements at identical conditions (same operator, same unit, same environmental conditions, short-term) are taken the standard deviation is the precision. Repeatability is the common cause variability in a measurement system. Typically identifies an equipment issue. Example: Same person doing the same activity gets the same results.

Repetition – Where many samples are measured from each experimental condition.

Replication – Number of times each set of experimental conditions is included in the experiment

Reproducibility – Repeated measurements by the different variables are consistent under same conditions. The difference in the average measurements made by different people using the same instrument, measuring the identical characteristic holding conditions as close as possible. For example, different people using same instrument, measuring identical characteristic. Typically identifies an issue with operators. Example: Two different people doing the same activity get the same results.

Risk Priority Number (RPN) – The numerical output of the FMEA that is calculated based on the severity, occurrence, and detection ability of the failure modes. The higher the RPN, the more critical the failure mode.

Rolled Throughput Yield (RTY) – The multiplication of all individual first pass yields of each step of the entire process.
(i.e., Step 1 Yield = 75%, Step 2 Yield = 90%, Step 3 Yield = 80%, RTY = 0.75 x 0.90 x 0.80 = 54%)

Sample – The particular collection from a population that we work with rather than the entire population.

Secondary Y – A metric related to the same process as the Project Y. It should improve as the Project Y improves but it is not the major focus of the project. Not all projects require a Secondary Y.

Should Map – A cross-functional process map done in the Improve Phase. A view of the future or improved process that shows who does the work and in what relative timeframe. An IS Map is required before a Should Map

Short Term Capability – Determines variation in the process assesses ability to meet specifications and permits short, intermediate and long-term goal setting. Requires about 30-50 observations.

Sigma, σ – Greek letter denoting the measure of the spread of the process (width of the distribution).

SIPOC – Supplier, Input, Process, Output, Customer – An alternative form of representing the process to include the impact of the customers and suppliers.

Six Sigma – Process mean is 6 process standard deviations from nearest specification limit. The term was coined by Motorola to express process capability in parts per million. A Six Sigma process generates a defect probability of 3.4 parts per million (PPM).

Special Cause Variation – Variation caused by forces acting from outside the usual/normal process.

Specification – The engineering requirement or customer requirement for judging acceptability of a particular characteristic. The Voice of the customer should be used to determine the specification.

Stability – a measure of how accurately the system performs over time. Control charts are used to monitor stability.

Stakeholder Analysis – A technique to identify key stakeholders in a process, their current and needed level of support for the project, and strategies for gaining the level of support needed for the project to succeed.

Standard Deviation – A measure of the spread of the process (width of the distribution).

Standardized Residuals – Residual minus mean divided by standard deviation

Statistical Control – The condition describing a process from which all special causes of variation have been eliminated and only common/random causes remain. Applies to both the mean (location) and standard deviation (spread). Control charts are used to determine whether or not a process is in control.

Statistical Thinking – A philosophy of learning and action based on the following fundamental principles:

- All work occurs in a system of interconnected processes,
- Variation exists in all processes, and
- Understanding and reducing variation are keys to success.

Super Y – Collection of related Six Sigma projects that provide opportunities to share metrics, best practices, learnings, and solutions. Examples include Inventory, Accounts Receivable, Manufacturing, Supplier, Customer, Commercialization, and Sales & Marketing.

True Value – If it could be know, the actual value of the item being studied, void of all sources of variation.

Tolerance – The range of the specification limits. Equal to the USL – LSL.

UCL, LCL – Upper Control Limit, Lower Control Limit; limits determined by the process beyond which we rarely expect to see data if the process is operated on target and in control. Usually these are set ±3s about the process target. Applies in theory only to normally distributed data.

Uncontrolled Inputs – Inputs that impact the outputs but are difficult or impossible to control (may also be controllable, just not under control currently).

USL, LSL – Upper Specification Limit, Lower Specification Limit; limits set by the downstream customer, internal or external, beyond which we should not operate the process.

Value and Time Analysis – A tool used to determine the amount of time spent in a process on value added vs. non-value added and work time vs. wait time.

Value Analysis Map – A type of process map that identifies the value added and non-value added steps of the process.

Variables Control Chart – A process control chart for a characteristic or parameter that has continuous values rather than discrete values such as counts.

Variance – A measure of spread of the process. It is the standard deviation squared.

Variation – Difference between individual measurements. Differences are attributed to common and/or special causes.

Variation: Common Cause – Variability introduced to a process that may not be controllable by the operator and may require outside assistance to reduce in size.

Variation: Special Cause – Variability introduced to a process that should be controllable by the operator of the process.

Voice of the Customer (VOC) – Customer feedback, both positive and negative, including the likes, dislikes, problems, and suggestions.

Voice of the Process (VOP) – Statistical data that is feedback to the people in the process to make decisions about the process stability and/or capability as a tool for continual improvement.

$\overline{X}, \overline{\overline{X}}$ - Sample subgroup mean and grand average of sample means.

Appendix 2 – One Minute Project Checklist

At any point in the project, do you understand…

☐ The problems you are trying to solve?

☐ Objectives and their measurement or scope?

☐ The tasks already completed and those necessary to successfully finish the project?

☐ Those affected by the project and those who can affect the project?

☐ The accuracy of the estimates and the assumptions which drive them?

☐ The resources, their availability, skills, styles and strengths and how we are planning to apply them?

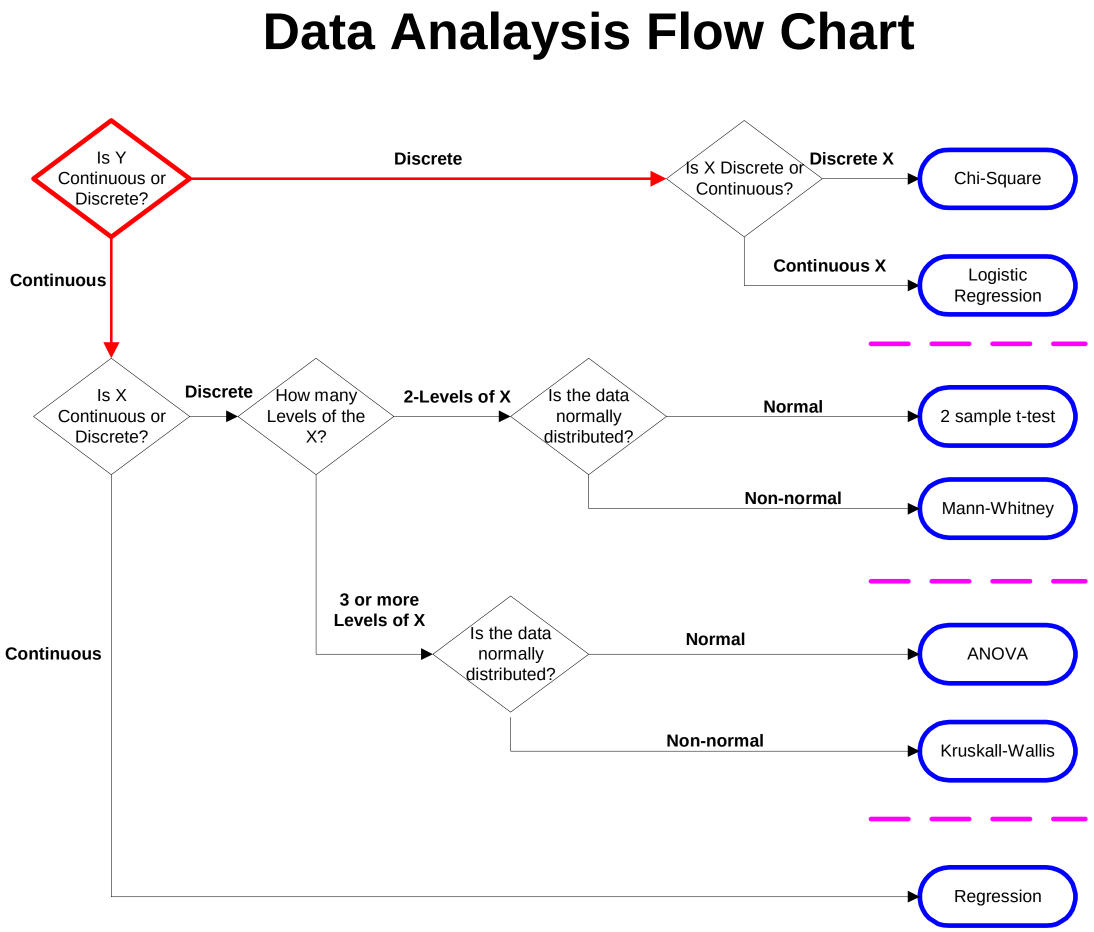
☐ The baseline schedule that the project can be completed within and how that compares to the deadline? (See the “project tracking” template in the ubertool.)

☐ Your project status compared to the schedule, and why?

☐ The expectations for the project, and the actions we are taking to maintain communications?

☐ What will it take to end the project successfully?

Appendix 3 – Data Analysis Flow Chart



Appendix 4 – Six Sigma Project Types

Six Sigma Portfolio – Project Types

Project Type	Characteristics	$Opportunity	Timing	Resources
1 - Classic Six Sigma BB for Operations (Manufacturing)	Gap between current and desired performance. Cause of problem not clearly understood. Solution unknown. Strong business case.	$500K + Real OI Savings, may have Cash or Growth Savings as well	4-6 mo	5-6 Team Members, Full time Leader
2 - Six Sigma BB for Transactional (Service), Improvement of a Business Process	Business process rather than manufacturing process. May have attributes data, or be non-data rich. May have extended pre-close period to verify Capability/Savings.	$5MM + Real Cash Savings, may have OI or Growth Savings as well	4-6 mo	5-6 Team Members, Full time Leader
3 - Six Sigma GB (Operations or Transactional), Replication Projects	Typically, smaller gap/ lesser $Opportunity. Fewer Resources required. Less extensive use of Six Sigma tools.	$100K + OI, Growth or Cash Savings	2-12 mo	2-3 Team Members, Part time Leader
4 - Business or Regulatory Projects which require an Immediate Response, Must Do It Projects	Consequences of not doing project are immense. May not utilize full Six Sigma toolset due to time constraint.	$MM's, Possibly too large and difficult to quantify	Immediate 1-4 mo	5-6 Team Members, Full time Leader
5 - DFSS (Product Development) Growth Projects	Begin with Customer Requirements, QFD, Value Analysis. Improved state of product "thrown over the wall". Reduced time to Sales.	NPV Calculation of Growth Savings, may be difficult to quantify	6-12 mo	Larger Teams
6 – Commercialization Projects (between DFSS & Classic Six Sigma)	Currently in Product Development process (Phase 1-3). Emphasis on MSA and Product Development FMEA. Existing team members.	NPV Calculation of Growth Savings, may be difficult to quantify	4-12 mo	Larger Team (existing)
7 - Re-Engineering (Process Development), Recovery Processing, or Product Transfers	Process understanding / Process validation. Cause of problem or solution may be known. Key tools MSA, Capability, FMEA.	$50K + OI Savings, may be difficult to quantify	6-12 mo	3-5 Team Members, Part time Leader
8 – Sourcing, Just Do It Projects	Cause of problem understood or solution known. Statistical analysis for qualification. Control Plan may be only key tool.	$50K + OI Savings, may be difficult to quantify	1-3 mo	2-3 Team Members, Part time Leader
9 - Scoping Projects, High-Level Processes (Manufacturing or Service)	The good side of Boiling the Ocean where you can see the ocean and spot the islands of opportunities (Candidates to Hopper).	None in the short term	1-3 mo	1 Part time Leader

Appendix 5 – Kickoff Meeting Checklist – Pre-work and During Meeting

Before Kickoff Meeting

1. Have project charter completed in GPS and approved by MBB.
2. Prepare financial worksheet (even if data is not yet available, the calculation method should be prepared for discussion).
3. Reserve meeting room and send meeting invitation to project team members (including Champion, Process Owner, and BB [if possible]) through Lotus Notes.
4. Prepare baseline data (initial capability), if available, to help communicate in kickoff meeting.
5. If need to drive project cycle time shorter, prepare high level process map and detail process steps (do not start mapping Y's and X's without project team involvement.
6. Search for relevant projects that you can replicate. Bring information to meeting.

During Kickoff Meeting

1. Introduce team members
2. Ask champion to discuss purpose of project and why it's important (include link to Business Critical Y).
3. Go through project charter with team and make sure everyone understands the following:
    a. Project number and name
    b. Process defect and how to measure it
    c. Process defects exists in and where starts/stops
    d. Project Y – clearly state Project Y as to improve some measurement from A to B in some time frame
    e. Project scope (in-scope and out-of-scope)
    f. Agreement on type of project (is this a process redesign project?)
    g. Measurement metrics (primary Y, secondary Y, counterbalance Y, financial benefit)
4. Propose and agree to project time frame (set preliminary milestones).
5. Identify what tools expect to use to help complete the project.
6. Goal, Roles and Responsibilities of each team member in this project (RACI of all team members and all planned tools is helpful).
7. Discuss data for measurement systems analysis and initial capability
    a. Data sources
    b. Data availability
    c. How data can be validated
8. Discuss any projects that will be replicated – are there others?
9. Start working on Process Map. If time allows and project isn't complicated, also do C&E.
10. Fix next 2-3 meeting dates.

After Kickoff Meeting

1. Activate project in GPS formally by doing the following:
    a. Change status to "Active"
    b. Change progress to "Green"
    c. Enter actual start date as the kickoff meeting date
    d. Select phase name to "Define" (if not yet done).
2. Post all project documents in PDR and send link to team members.
3. Send meeting notices for next 2-3 meetings.
4. Project Defect – can we specifically say what is causing the pain?

Appendix 6 – Analysis Roadmap – Full and Fractional Factorial DOE’s

The same roadmap can be used for both Fractional or Full Factorial DOE’s. If doing a Full Factorial DOE, do **not** do the fractionation.

Create a Factorial Design

① **Determine number of levels**

② **Determine number of factors**

③ **Determine size of fraction**

- What will be the design resolution?
  - Consider the aliasing structure (Confounding of factors)

④ **Centerpoints? Replicates? Repetitions? Blocks?**

⑤ **Randomize runs or Standard order?**

⑥ **Run Experiment & Collect Data**

① **Did you create the original design matrix?**

- NO: Define Factorial Design, then begin analysis
- YES: Begin analysis
- Confirm all terms are in the analysis

② **Create graphs: Normal and Pareto**

- Are there any factors or interactions that are significant?
  - NO: Re-evaluate level setting of factors (Bold vs. Narrow)
  - YES: Look at significant factors using Factorial Plots.
    - Evaluate the aliasing structure.
      - What is the most likely “driver” of the effect?

③ **Is there a significant interaction(s)?**

- NO: Proceed to evaluate significant Main Factors
- YES: Run an Interaction Plot.
    - Evaluate relationship between factors.
    - What factors are most likely to be involved in interactions?
    - Decide the best settings for each factor as it relates to the Response (Best Operating Condition)

④ **Is there a significant Main Factor(s)?**

- NO: Proceed to Reducing the Model
- YES: Run a Main Effects Plot.
  - Consider any aliasing with interactions
  - Evaluate the slope of the line.
  - Determine the best level settings for each factor as it relates to the Response (Best Operating Condition)

⑤ **Reduce Model - Analyze Factorial Design**

- Remove insignificant terms from the original model
- Turn off graphs (Normal and Pareto)
- Store Standardized Residuals and Fits

⑥ **Develop Y=f(x) model**

- In Session window, Use coefficient values to create model

⑦ **Determine R^2**

- Run Balanced ANOVA
  - Enter the final model
- Review ANOVA table in Session window
- Cut and Paste SS column in to Minitab Worksheet
- Calculate SS_{factor}/SS_{total} to get %variation related to factor, interactions, and error term

⑧ Evaluate Residuals

- Run Residual Plots
  - Are the residuals normally distributed? (Normal Plot / Histogram)
  - Are the residuals stable? (Individuals Chart)
  - Is the data in the “Residual vs. Fits” Plot randomly distributed?
    - **NO**: Evaluate possible factors missing from the model
      - Evaluate transformation opportunities
    - **YES**: Model is good representation of Y=f(x)

① Was the desired Response value/range found?

- **YES:** Set factors of study to levels determined in DOE, Set and Run process. Evaluate Response using control chart methods.
- **NO:** Determine if another DOE is necessary
  - How many factors?
  - Same factors, new levels?
  - Same factors with additional factors?
  - All new factors?
  - Full or Fractional?
  - Block? Repeats? Replicates?

Appendix 7 – Change Acceptance Tools

A wide variety of tools exist to help address change and team issues within a project. The following are a sampling of these tools. See your Black Belt or Coach for assistance.

Link DMAIC and Change Acceptance Tools

The following template can be found in “Link DMAIC and Change Acceptance Tool v1-1.xls” in the Information and Tools Database. The file contains templates for each of the tools listed.

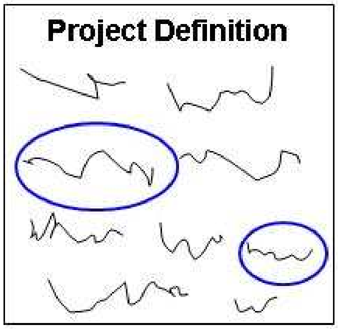
Q x A = E

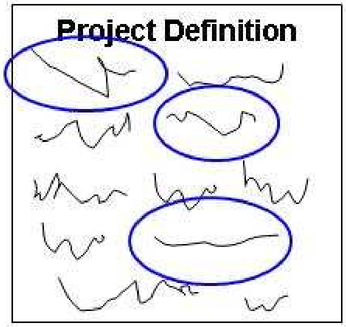
Quality of Solution x Acceptance of Change = Effectiveness of Project

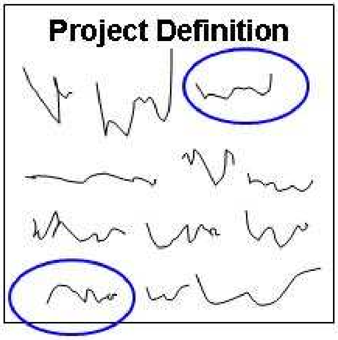
	Define	Measure	Analyze	Improve	Control
Quality of Solution	Project Charter	Process Map Cause & Effects Matrix Measurement Systems Analysis Initial Capability	FMEA Multi-Vari	Business Process Redesign Pilot Simulation Experiment	Control Plan Training Final Capability
	Chartering Process	**Engagement & Acceptance Planning “Shared Vision” “Engaged Stakeholders”**	**Map the Transition**	**Implement the Change and Adjust**	**Sustain the Gain**
Acceptance of Change	Align team with charter * In/Out of Frame * 15 Words * Elevator Speech	Identify potential resistance * Force Field Analysis * Resistance dialog	Quantify & resolve resistance * Force Field Analysis * Resistance dialog	Plan Systems & Structures transition * Transition Map * More of / Less of * Systems & Structures Wkst	Put controls around Systems & Structures * RACI Matrix * Training
	Identify key participants, obtain engagement / form team * Stakeholders Analysis * WIIFM * RACI Matrix	Identify Stakeholders & Develop influence strategy * Stakeholders Analysis * WIIFM * Influence Strategy * RACI Matrix	Identify necessary new behaviors * Transition Map * More of / Less of * RACI Matrix	Review stakeholders & finalize influence strategy * Stakeholders Analysis * WIIFM * Influence Strategy * Polarity Map	Celebrate!
	Establish business case * Force Field Analysis * SWOT * Leadership Dialog	Assess team * GRPI * Team Performance Model * Team Power	Assess team * GRPI * Team Performance Model * Transition Curve * Team Power	Assign roles & responsibilities * RACI Matrix	
		Create communication plan * Communication Plan			

15 Words

- **What:**
  - 15 word statement of project definition/scope
- **Why:**
  - Craft positioning statement / build process definition
  - Good group process tool:
    - Obtain opinions of all team members
    - Construct or reach team consensus
  - Helpful in writing elevator speech
- **When:**
  - Define phase – while writing project charter, elevator speech is based on this tool
  - Mid-stream – bring people back to same page/definition/scope of project
- **Need:**
  - Large sheets of paper on wall
  - Markers for all participants
- **How:**
  1. Ask each team member (or pairs of team members) to write in 15 words or less the project definition and scope on a large sheet of paper
  2. Post all responses and check for agreement
  3. Double check all fuzzy words by circling them and asking
     - "What does it look like?"
     - "How will we know it when we have it?"
  4. Identify key words or phrases team feels best about
  5. Finalize on project definition and scope on one sheet with team agreement

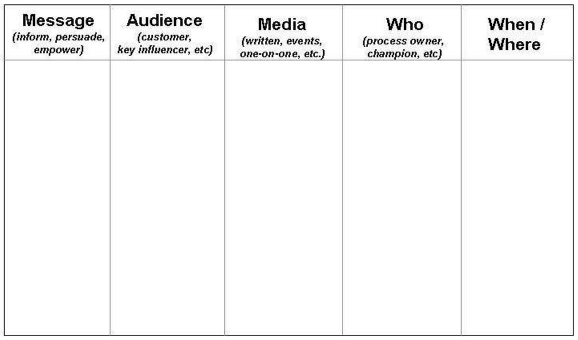






Communication Plan

- **What:**
    - Plan for communicating changes to key stakeholders
- **Why:**
    - Trigger dialog with champion and process owner on who to communicate to, what method, what media, who's doing it, etc
    - Use within team for communicating to team members and coalition (Process Owner, Champion, Black Belt, etc)
- **When:**
    - Define phase
        - After identified key stakeholders (Stakeholders Analysis) and what information they need (WIIFM)
        - Within team to identify types of communication needed within team players (Process Owner, Champion, etc)
    - Improve phase before implement improvements
    - Every project should have one
- **Need:**
    - Large easel sheet or computer with communication template
- **How:**
    1. Identify:
        - What needs to be communicated (message)
            - When change will occur
            - How change will impact them
            - What information is needed from them
            - What you need them to do
        - Why should it be communicated (purpose)
            - Create need for change
            - Ensure understanding of process improvement



Message *(inform, persuade, empower)*	Audience *(customer, key influencer, etc)*	Media *(written, events, one-on-one, etc.)*	Who *(process owner, champion, etc)*	When / Where

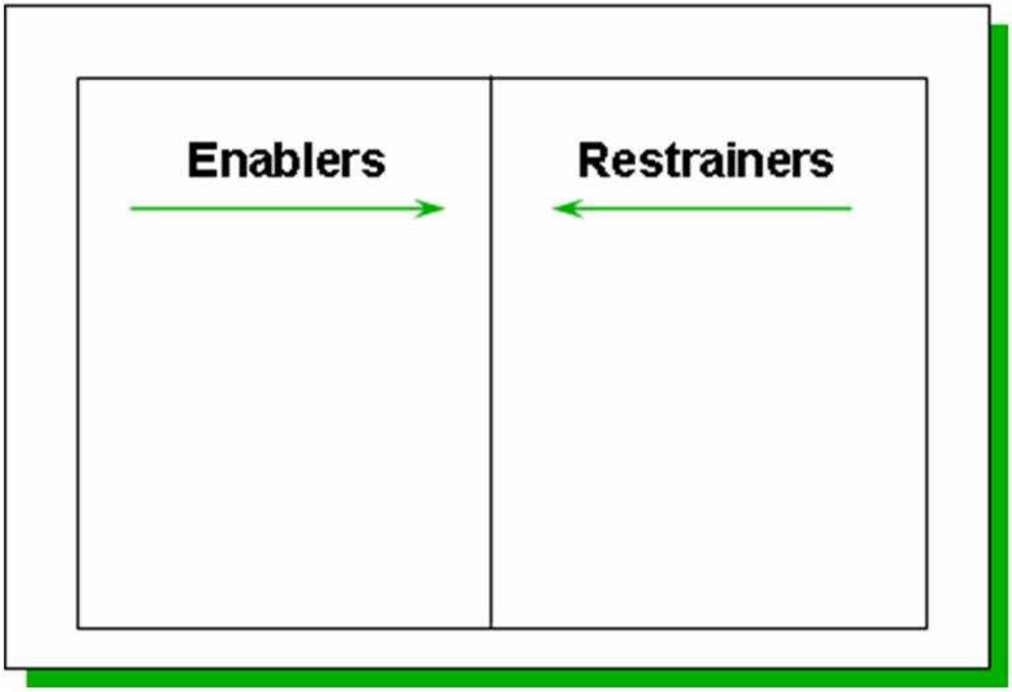
        - Who needs to be communicated to
            - Process owner
            - Champion
            - Team members
            - Key influencers
            - People affected by change
        - Who needs to be communicated from
            - Key influencer
            - Project leader
            - Team member
            - Champion
            - Process owner
        - How should it be communicated (Media)
            - Method of communication (e.g. eMail, posters, etc)
            - Determine who should do communication (team member, champion, etc)
        - When should the communication occur
            - Appropriate timing within project
    2. Assign responsibilities for communication plan tasks (RACI Matrix is helpful)
    3. Follow communication plan
    4. Update plan throughout project

Elevator Speech

- **What:**
  - Clearly and simply state need for change and future state
  - “Pitch” to share with key stakeholders
- **Why:**
  - Good group process tool:
    - All contribute
    - All in agreement with clear process understanding
    - Team consensus
  - Good sales tool - management understands it!
  - Good when publishing project
- **When:**
  - Define phase when writing project charter
  - First team meeting and/or first meeting with process owner/champion
  - Use 15 words exercise to help develop elevator speech
- **Need:**
  - PC or large easel sheets on wall
- **How:**
  1. Together team reviews project scope, process definition, need for change, etc
  2. Individual team members make notes as they form own version of speech. Well crafted elevator speech ought to generally, follow this simple four part formula:
     a. "Here's what our project is about............",
     b. "Here's why it's important to do...........",
     c. "Here's what success will look like............", and
     d. "Here's what we need from you..........”
  3. After quiet "rehearsal time", team members pair up and deliver their speech to their partner and receive feedback on what works / doesn’t work
  4. Together team identifies a speech they all like best and/or begins to put together parts from a variety of individual speeches to create a new speech all feel comfortable with
- **Tips:**
  - Important for each project team member to practice final speech before delivering it to any key constituents
  - Practice one-on-one with another team member
  - Encourage team members to practice on friends if subject is complex or confusing
- **Option:**
  - Have a volunteer deliver elevator speech to rest of team. Other members play roles of key constituents (like engineering, marketing, management, etc.). Listen and critique speech.

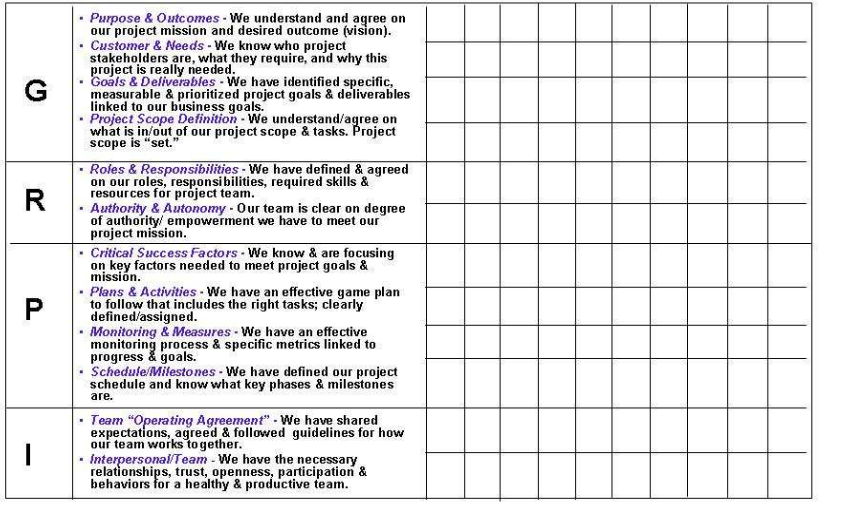
Force Field Analysis

- **What:**
  - Identifies Enablers & Restrainers to project implementation
  - Identify enablers to strengthen and restrainers to lessen or eliminate
- **Why:**
  - Look at forces in internal and external environment that will make change last or hinder change over long term
  - Help team develop plans to ensure change becomes integrated into "fabric" of organization. Can be applied to project as a whole, or a particular part of project.
- **When:**
  - Define: "predict" what will help or hinder project (assumptions should be validated a number of times as project progresses)
  - Analyze/Improve: Most effective when some significant work has already been done on overall project and strong resistance has been encountered
- **Need:**
  - Easel sheets & Post-it Notes
- **How:**
  1. Pass Post-it notes to everyone and place two large easel sheets on wall labeled “Enablers” and “Restrainers”
  2. Ask everyone to identify things that will enable project and things that will restrain project and place on sheets
  3. Agree on an final collection of enablers and restrainers (sort out any people see quite differently; "I see _______ as an enabler and you have it as a restrainer.")
  4. Prioritize items on each list and pick those enablers team thinks can be further strengthened and those restrainers they think must be lessened or eliminated
- **Option:**
  - Restrainers can be further studied for "root cause" using a Fishbone diagram technique or FMEA.



G.R.P.I. Checklist

- **What:**
  - Assess project team status
  - Challenge team to consider four critical and interrelated aspects of teamwork: Goals, Roles, Process, Interpersonal
- **Why:**
  - Team tool to see how team is interacting
  - Useful in identifying team disconnects
  - Invaluable in helping a group become a team – when newly formed or when exist but haven't looked at teamwork
  - Get more information on whether team is in agreement than quick verbal check
- **When:**
  - During any phase
  - Proactive: Use at end of first/second meeting to check if team is on same page
  - Reactive: If something not right with team, use to identify discrepancies / disconnects
- **Need:**
  - G.R.P.I. checklist handout
- **How:**
  1. Distribute copies of G.R.P.I. checklist to team members
     a. GOALS - How clear and in agreement are we on the mission and goals of our team/projects?
     b. ROLES - How well do we understand, agree on, and fulfill the roles and responsibilities for our team?
     c. PROCESSES - To what degree do we understand and agree on the way in which we'll approach our project AND our team?
     d. INTERPERSONAL - Are the relationships on our team working well so far? How is our level of openness, trust and Acceptance?
  2. Ask team members to individually fill out sheet
     a. Place an X in one color where they think they are at related to the project
     b. Place an X in another color where they think their team is at related to the project
     c. Give checklist anonymously to team leader for aggregation
  3. Meet as a group to discuss checklist discrepancies and to resolve issues
- **Tip:**
  - Can use to check on how team is working from time to time. Ask team members to vote on each of the dimensions using a "fist-to-five" technique (five fingers = great; a fist = zero progress).

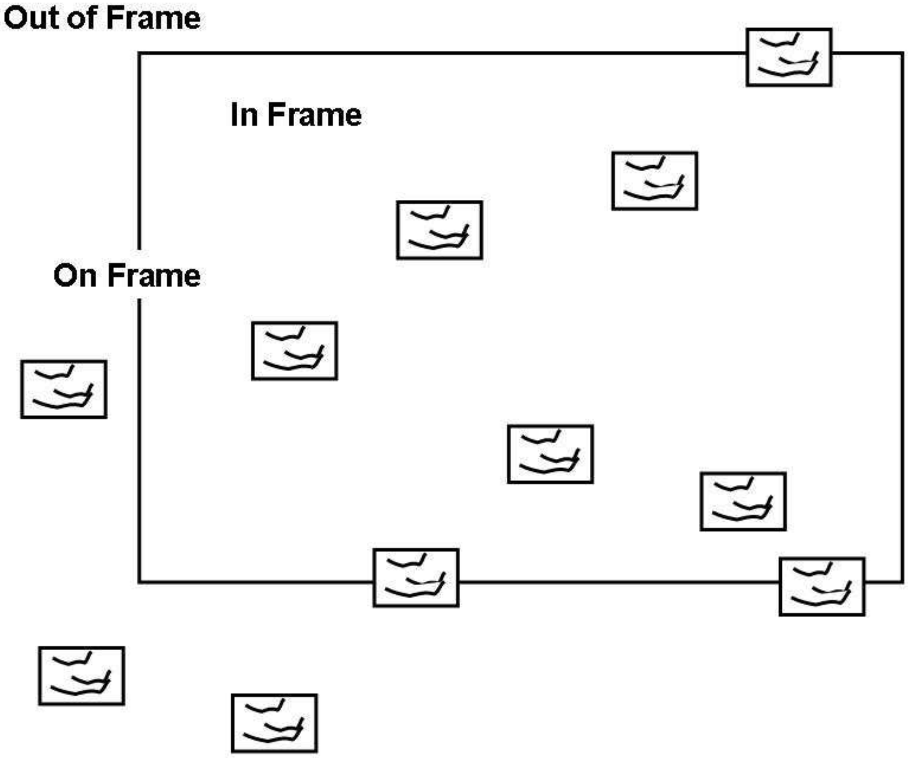


How would you rate the degree to which your team presently has CLARITY, AGREEMENT, and EFFECTIVENESS on the following GRPI-related elements?:

		0%				50%					100%
G	▪ *Purpose & Outcomes* - We understand and agree on our project mission and desired outcome (vision).										
	▪ *Customer & Needs* - We know who project stakeholders are, what they require, and why this project is really needed.										
	▪ *Goals & Deliverables* - We have identified specific, measurable & prioritized project goals & deliverables linked to our business goals.										
	▪ *Project Scope Definition* - We understand/agree on what is in/out of our project scope & tasks. Project scope is "set."										
R	▪ *Roles & Responsibilities* - We have defined & agreed on our roles, responsibilities, required skills & resources for project team.										
	▪ *Authority & Autonomy* - Our team is clear on degree of authority/ empowerment we have to meet our project mission.										
P	▪ *Critical Success Factors* - We know & are focusing on key factors needed to meet project goals & mission.										
	▪ *Plans & Activities* - We have an effective game plan to follow that includes the right tasks; clearly defined/assigned.										
	▪ *Monitoring & Measures* - We have an effective monitoring process & specific metrics linked to progress & goals.										
	▪ *Schedule/Milestones* - We have defined our project schedule and know what key phases & milestones are.										
I	▪ *Team "Operating Agreement"* - We have shared expectations, agreed & followed guidelines for how our team works together.										
	▪ *Interpersonal/Team* - We have the necessary relationships, trust, openness, participation & behaviors for a healthy & productive team.										

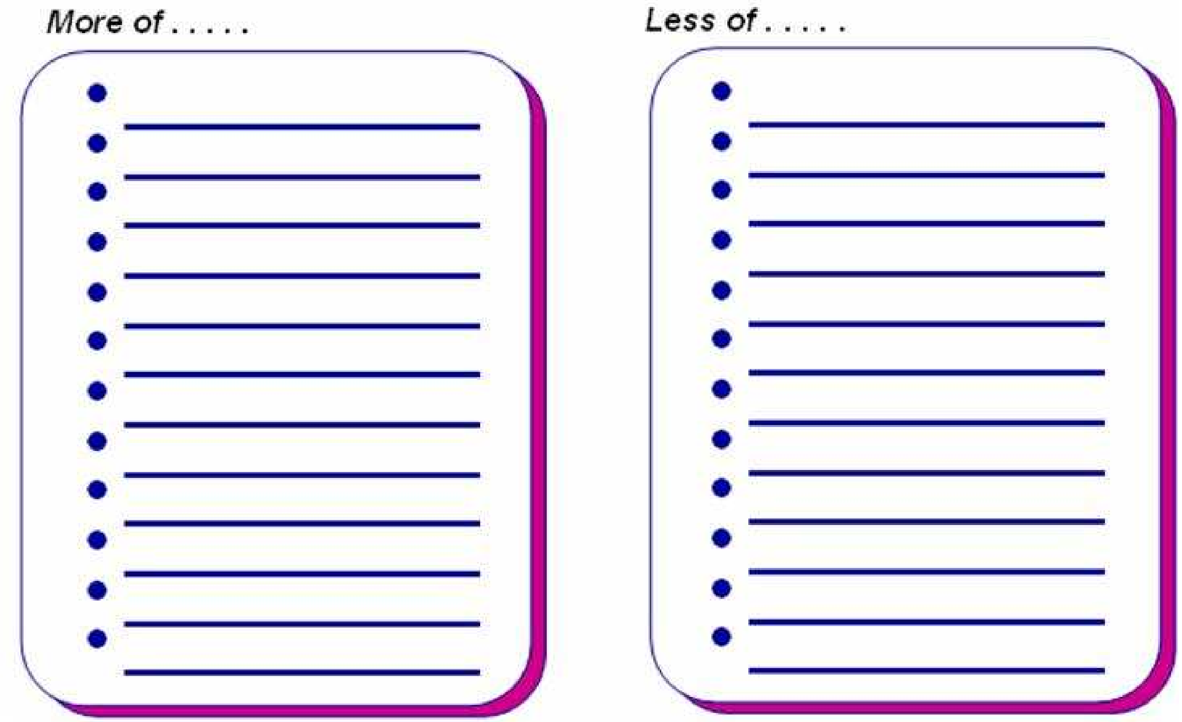
In/Out of Frame

- **What:**
  - Defines what is in and out of project scope
- **Why:**
  - Useful in obtaining consensus
  - Uncovers potential issues
  - Brings discussion to higher level
- **When:**
  - During Define phase – when working on project charter
  - Keep results visible when working on all tools (Process Map, Cause & Effects Matrix, FMEA)
- **Need:**
  - Large sheet of paper on wall
  - Post-it notes for all team members
- **How:**
  1. Draw box on large Post-it Easel Pad
  2. Pass out 3x3 Post-it Notes to all team members
  3. Each team member to write down what they believe of process, procedures, tools, practices to be in and out of scope (do not write on note whether it is "in scope" or "out of scope")
  4. Team members to place their Post-it Notes:
     a. outside of frame if topic is "out of scope"
     b. inside of frame if topic is "in scope"
     c. on frame if unsure
  5. Silently move Post-it Notes based on their thoughts of whether topic is "in scope", "out of scope", or "unsure"
  6. When Post-it Notes are no longer moved, dialog with team on placement of topics to ensure reach consensus
- **Tips:**
  - Update project charter to reflect final decisions
  - Keep visible as work on project



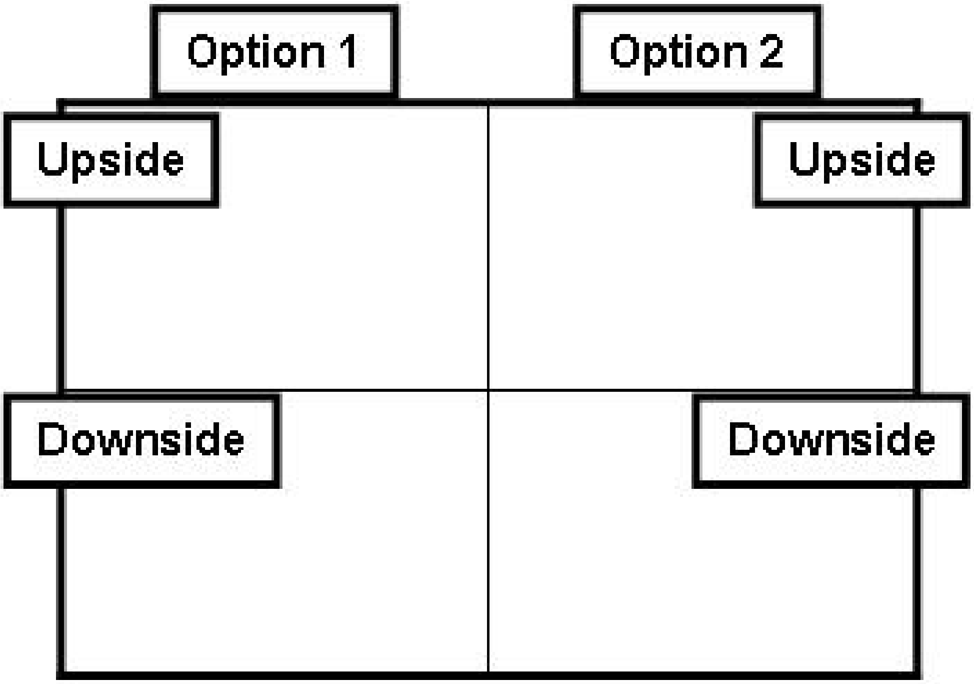
More Of/Less Of

- **What:**
  - Helps measure if people involved in your process have made necessary changes to sustain process improvements
  - About human behaviors, things people actually do
  - Don't focus on changing attitudes – people resist. Change expectations and behavior will change.
- **Why:**
  - What needs to be done in order for change to succeed?
  - What do people need to do more of for the project gains to be achieved?
  - What do people need to do less of for the project gains to be achieved?
  - Uncovers potential issues
- **When:**
  - During Improve phase – when working on determining what are needed behaviors and how day-to-day lives will be changed
- **Need:**
  - Large sheet of paper on wall
  - Post-it notes for all team members
- **How:**
  1. Pass out 3x3 Post-it Notes to all team members
  2. Each team member writes down what they believe are behaviors that are needed more of or less of when the project is completed
  3. Team members place their Post-it Notes under the headings "More of" or "Less of"
  4. Once all Post-it Notes are on board, dialog with team on placement of items to ensure reach consensus
  5. Discuss how to ensure needed behavior changes will occur
- **Tips:**
  - Validate with key stakeholders to reflect final decisions
  - Keep visible as work on improving project



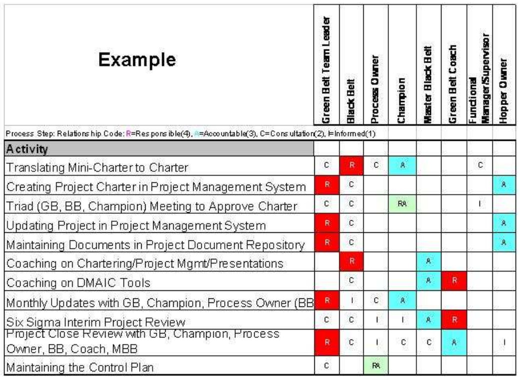
Polarity Map

- **What:**
  - Explore positives/negatives to each side of situation / improvement
  - Put action plans in place to keep balance between positives of solutions – with minimal time spent in negative areas
- **Why:**
  - Helps clarify issues facing both sides and helps group plan actions that will keep them primarily in positive quadrants of both viewpoints.
  - Group (as a whole) needs to manage change dilemma on an ongoing basis. Keeping balance between polarities is an ongoing management responsibility. We cannot ignore these issues.
- **When:**
  - Improve – Identify different sides of situation; discuss positives and negatives
- **Need:**
  - Large easel sheets on wall
- **How:**
  1. Make two flip charts:
  2. Title one sheet with first situation/solution and other sheet with second situation/solution
  3. On each sheet, write “Upside” at top and “Downside” near middle
  4. Each group brainstorms ideas to fill in their chart
  5. Place each flip chart side by side so group can clearly see benefits and risks of both
  6. Each group shares their list of upsides first (alternating groups) – ask for input from other group
  7. Each group shares their list of downsides second (alternating groups) – ask for input from other group
  8. Remind them we want to stay focused on upsides of both scenarios!



RACI Matrix

- **What:**
  - Assignment of roles and responsibilities
- **Why:**
  - Helps clarify role assignment
  - Sorts out who is *Responsible*, *Accountable*, *Consulted* and *Informed*
  - Brings order out of chaos especially for non-sequential processes
  - Can be used for process steps, tasks, assignments, input variables….. To establish roles and accountability
- **When:**
  - During any phase & on every project
    - Define - Identify roles & responsibilities for project
    - Measure - Identify roles & responsibilities for initial process map
    - Improve - Identify roles & responsibilities for "should" process map or cross functional process map (especially Business Process Redesign)
    - Control - Communicate roles & responsibilities for "should" process map or cross functional process map in control plan
- **Need:**
  - PC with RACI Matrix
- **How:**
  1. Determine purpose of doing RACI Matrix
     - Identify roles & responsibilities for project
     - Identify roles & responsibilities for initial process map
     - Identify roles & responsibilities for "should" process map or cross functional process map
     - Communicate roles & responsibilities for "should" process map or cross functional process map
  2. Prior to completing RACI Matrix, create operational definitions for:
     - ***Responsible*** – people with ultimate responsibility for taking action to complete process step or activity
     - ***Accountable*** – one person with ultimate accountability for making sure process step or activity is completed
     - ***Consultant*** – consulting resource(s) for process step or activity
     - ***Informed*** – people to be kept informed on status of process step or activity
  3. Across top of RACI Matrix list stakeholders
  4. Down side of RACI Matrix list tasks or steps
- **Tips:**
  - Important to have team dialog while filling out RACI Matrix – do not do alone
  - Try to limit number of people "responsible" for a given process step, task, etc., after process is improved



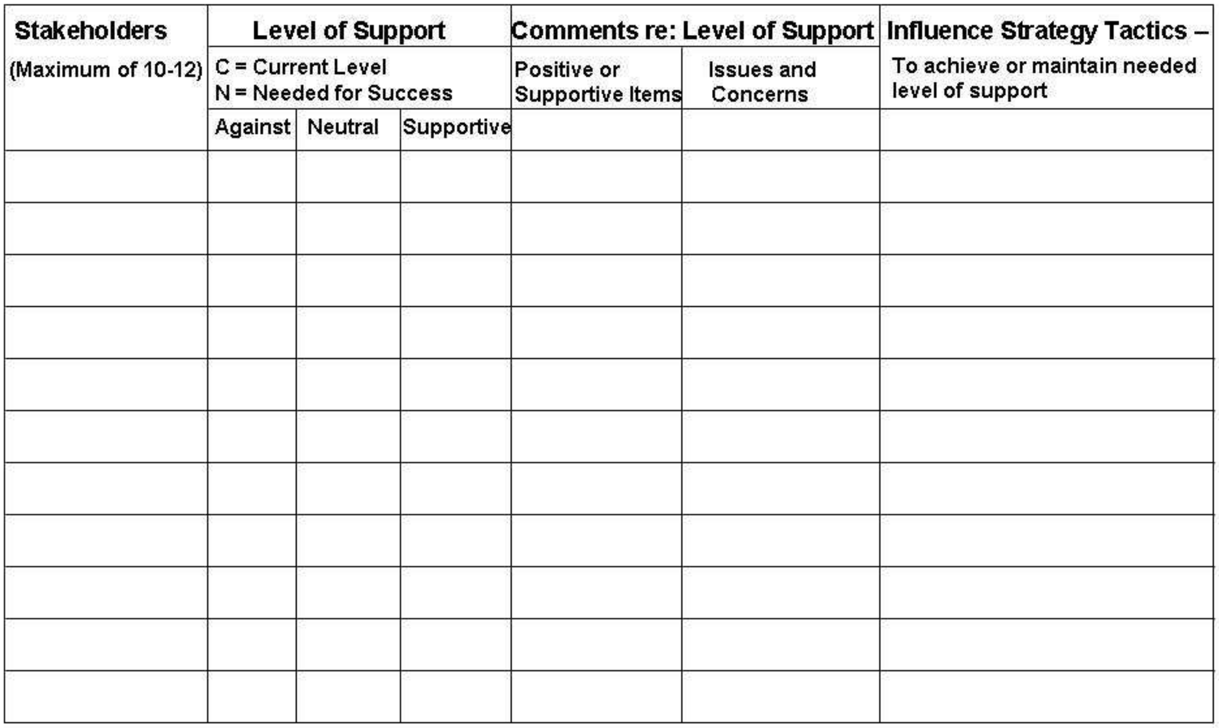
Example	Green Belt Team Leader	Black Belt	Process Owner	Champion	Master Black Belt	Green Belt Coach	Functional Manager/Supervisor	Hopper Owner
Process Step: Relationship Code: R=Responsible(4), A=Accountable(3), C=Consultation(2), I=Informed(1)								
Activity								
Translating Mini-Charter to Charter	C	R	C	A			C	
Creating Project Charter in Project Management System	R	C						A
Triad (GB, BB, Champion) Meeting to Approve Charter	C	C		RA			I	
Updating Project in Project Management System	R	C						A
Maintaining Documents in Project Document Repository	R	C						A
Coaching on Chartering/Project Mgmt/Presentations		R			A			
Coaching on DMAIC Tools		C			A	R		
Monthly Updates with GB, Champion, Process Owner (BB	R	I	C	A				
Six Sigma Interim Project Review	C	C	I	I	A	R		
Project Close Review with GB, Champion, Process Owner, BB, Coach, MBB	R	C	I	C	C	A		I
Maintaining the Control Plan	C		RA					

Stakeholder Analysis

- **What:**
  - Helps team identify the stakeholders, what their issues are with the change, and what level of supported is needed
  - Team determines what are stakeholders' issues and concerns, who can best influence each individual, and how they are best influenced
- **Why:**
  - Understand who is affected by change (Stakeholders)
  - Understand stakeholders' reaction to change
  - Plan effective influence strategy for successful change
- **When:**
  - During any phase & on every project
    - Define – Identify key stakeholders for project or identify key team members for project or match team's expectations
    - Measure – Identify obstacles and support
    - Control – Identify key stakeholders for change
    - Anytime – When "bring on board" a new stakeholder who has just emerged
- **Need:**
  - PC with Stakeholder Analysis template
- **How:**

1. Identify key stakeholders (limit to 8-12 people or groups). They should have control of critical resources, could block, must approve, or own key work processes.
2. Down left side of chart list each stakeholder and discuss where each is currently in relation to change initiative. Examine objective and subjective evidence (fact and opinion) of where individual is at.
3. Discuss where each *needs to be* for change initiative to be successful. Remember, some stakeholders need only be shifted from "against" to "neutral".
4. List comments regarding stakeholders' level of support and identify their (potential) issues with change
5. Develop an influence strategy
    - How does this person like to be informed? Picture person? Data person?
    - What history has this person experienced that needs to be understood when talking with them?
    - Is there a part of the project this person could do which would help garner their support?
6. Assign influence strategy implementation tasks to specific individuals with dates/times for completion

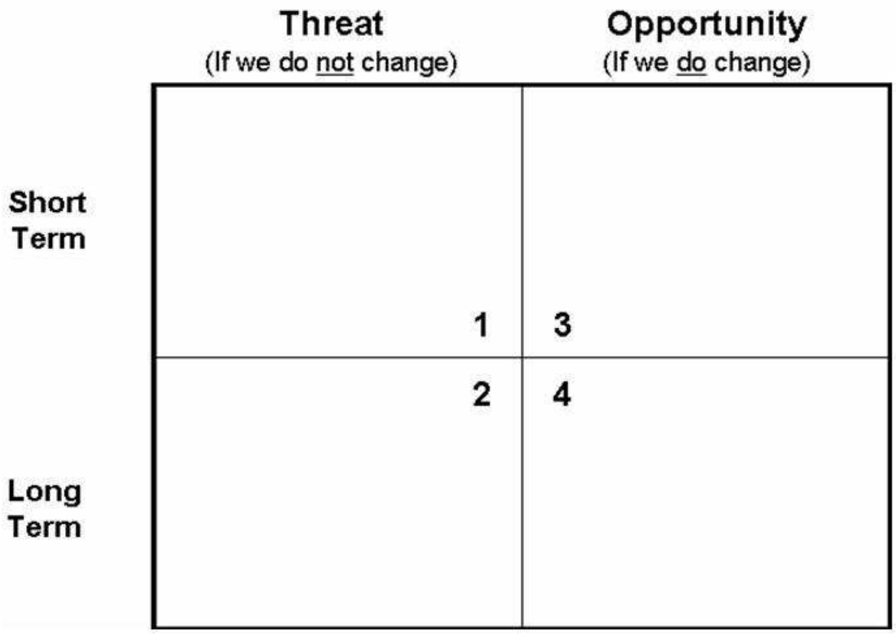
- **Tips:**
  - Make sure include all players – including customers
  - Use with WIIFM and Enabler/Restrainer
  - Not about being "good" or "bad" – rather about how key individuals view merits of required changes
  - Careful thought needs to be given to:
    - *Who* will have most impact on stakeholder
    - *What* is nature of "message" need to deliver
    - *How* and *when* should influence process begin
  - Some teams combine this discussion with formulation of their communication strategy/plan for change
  - Look for logical relationships between and among stakeholders in terms of who might assist team in gaining support of others. For example, if a key stakeholder who is "supportive" is also a "thought leader" for others on list, it might be useful to enlist his/her support in shaping thinking of other against or neutral stakeholders.
  - Totally worthless unless people can be honest
  - Keep results within team



Stakeholders	Level of Support			Comments re: Level of Support		Influence Strategy Tactics –
(Maximum of 10-12)	C = Current Level N = Needed for Success			Positive or Supportive Items	Issues and Concerns	To achieve or maintain needed level of support
	Against	Neutral	Supportive			

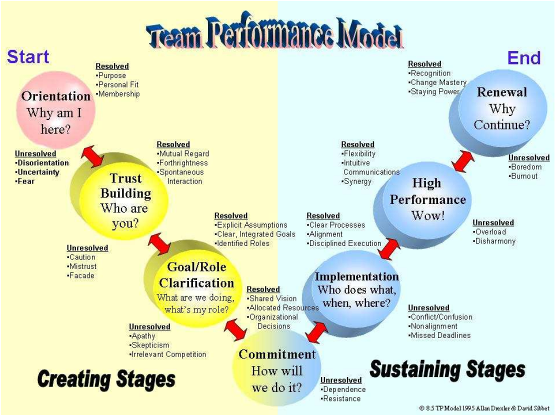
Strengths, Weaknesses, Opportunities, Threats (SWOT)

- **What:**
  - Frame need for change as a threat and opportunity over both short and long term
  - Get attention of key stakeholders in a way to ensure their involvement beyond what can be gained from a short-term sense of urgency
- **Why:**
  - Build significant case for change for project
  - Helps team frame need for change more broadly
- **When:**
  - Define – Statement of need with clear sense of why change initiative is essential to do at this point in time
- **Need:**
  - Easel sheets of paper
- **How:**
  1. Each team member picks one quadrant that represents the need for change for this project and writes notes on why
  2. Team members share their thoughts and dialog the similarities and differences
  3. Each team member writes a couple sentence statement incorporating all of the quadrants stating the need for change
  4. All read their statements and team utilizes all statements to create a group statement that encompasses the best of each individual effort
  5. Modify statement to appeal to key stakeholders (sales, manufacturing, marketing, etc.).
- **Tips:**
  - Sometimes helpful to do this tool in partnership with Stakeholders Analysis
  - Remember – framing need for change is an iterative process. As project moves forward, more information and perspectives will be gathered and should be factored into explaining need for project.
  - Different audiences or constituent groups will be attracted to different ways of framing need for change. Team must learn how to communicate this need in a "language" that will appeal to specific constituent group or individual.



Team Performance Model

- **What:**
  - Identify specific team building needs each team member has or group needs
- **Why:**
  - Proactively begin to answer key questions of each step in model to accelerate team formation and project completion
  - Team leader send eMail to team with questions to informally check
- **When:**
  - During any phase
  - When have problem on team and don’t know what it is – use G.R.P.I. Checklist first then model
  - Proactively during team formation
  - Link to team communication plan
- **Need:**
  - Questions
- **How:**
  1. Team leader send eMail to team with questions
     - *Stage 1 – Orientation*
       - Why am I here?
       - Do I belong?
       - Can I contribute something worthwhile?
       - Do I want to be here?
       - Do I understand the task?
       - Can I throw in with the group/task?
       - Will my skills be used?
       - Will my unique point of view be heard?



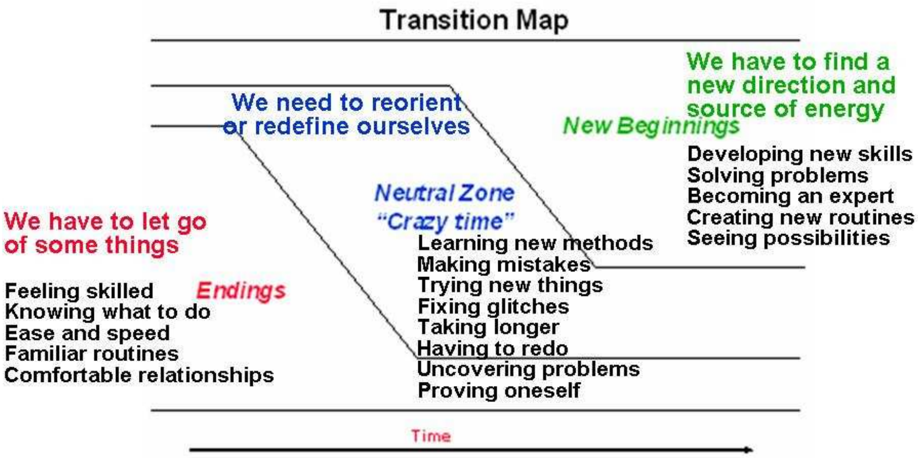
     - *Stage 2 – Building Trust*
       - Who are you?
       - What will you expect of me?
       - Can you be relied upon?
       - Do you know your craft?
       - Can you maintain confidentiality?
       - Are you dedicated to the task?
       - Do you have ulterior motives?
       - Do you have hidden agendas?
       - Will you accept me as I am?
       - Will you accept my ideas?
     - *Stage 3 – Goal/Role Clarification*
       - Precisely what must the team do?
       - Are all of the options surfaced?
       - Are all of the issues identified?
       - What are reasons for choosing among options?
       - Is there agreement on group goals?
       - Is the group operating from same premise?
       - Are goals clear?
       - Is there consensus on group purpose?
       - Is there consensus on group task issues?
       - Are personal goals clear, in the open?
       - Does the vision / mission exist to help organize work?

- *Stage 4 – Commitment*
    - Is the team ready to act?
    - How do we manage the team?
    - Who has what responsibilities?
    - Are all responsibilities addressed?
    - Are role conflicts resolved?
    - Are responsibility gaps / overlaps resolved?
    - How (method) are responsibilities divided?
    - Have we chosen systems / processes / tools to manage the overall task?
    - Do we all understand the steps of the processes we've chosen to manage the task?
    - Do all own responsibility for success?
    - How do we handle stakeholders needs?
    - Who will address stakeholders?
- *Stage 5 – Implementation*
    - How will things be done?
    - Is there a project plan?
    - Who will do what, when, where?
    - Are "non-must do" tasks discarded?
    - Is task ambiguity minimized?
    - Are task sequence and timing correct?
    - Is there a mesh and balance in the tasks?
    - Is the schedule clear to all?
    - Do we get things done or just talk about it?
    - Is work integrated, not segmented?
    - Do members know the big picture and their fit?
- *Stage 6 – High Performance*
    - Does activity of the team flow?
    - Are boundaries and limits broken?
    - Is everyone in the groove, are things clicking?
    - Is activity focused and coordinated?
    - Is communication intuitive?
    - Is there evidence of synergy?
    - Is performance a result of crisis or work?
    - Is there openness, affinity and consistency of behavior?
    - Is striving for high performance a mistake?
- *Stage 7 – Renewal*
    - Why continue?
    - Answer positive – renewed purpose
    - Answer negative – frees us to be elsewhere
    - Rewards and recognition
    - Celebration and finalization

2. Team members send responded (anonymously) to team leader
3. Team discusses summarized responses

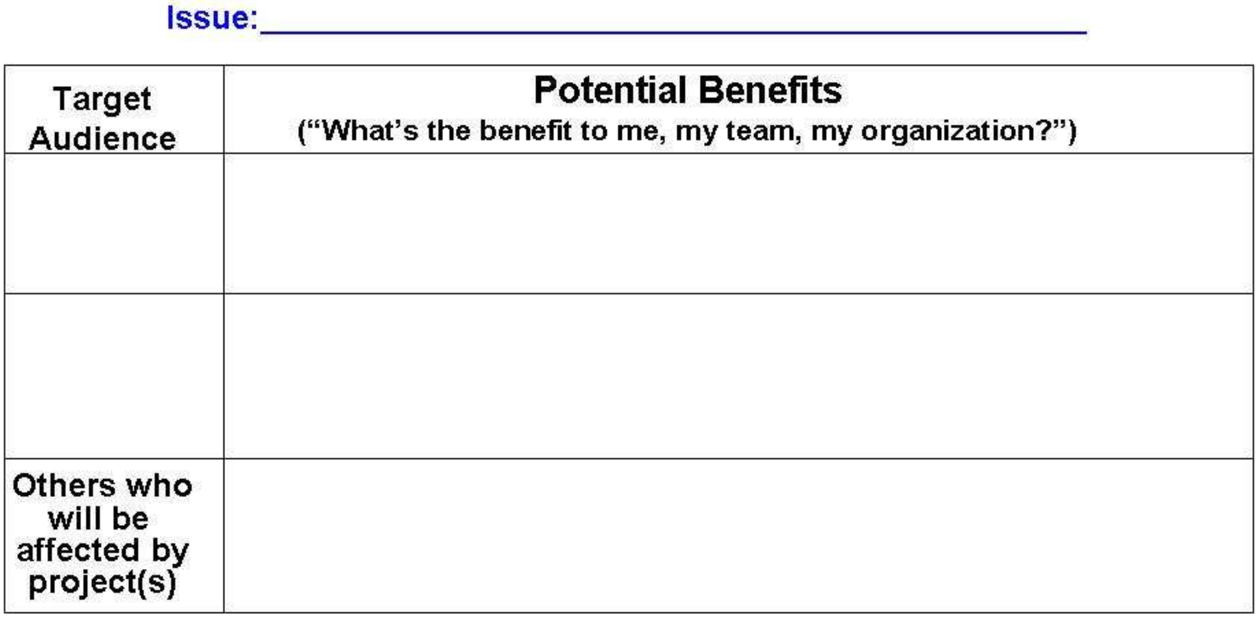
Transition Map

- **What:**
  - Identify what can go on during a transition
- **Why:**
  - Brainstorm with a team how they are thinking about a particular change
  - Anonymously identify issues/challenges that may occur during transition
  - As Gantt chart to help team during transition
- **When:**
  - Improve: Document potential issues and identify items needed for successful transition
  - Control: Identifies implementation issues
- **Need:**
  - Large sheets of paper on wall
  - Post-it notes
- **How:**
  1. Place 3 large sheets of paper on wall with titles of Ending, Crazy Time, Beginning
     - Endings:
       - Define what is ending
       - Honor what got you to where you are
       - Finalize what won't be done any more, and how it will be handled
       - Take the best of the past with you but pack light
     - Beginnings:
       - Define new tasks and processes
       - Design how tasks and processes fit together and fit into the organization
       - Define people's new roles
       - Define expected results
       - Define timelines
       - Select people for new jobs
       - Modify change plan as needed to succeed
       - Establish new accountability system
     - Neutral Zone/Crazy Time:
       - Plan to get people from current place to new place
       - Job, work group and team training
       - Communication of strategy, change plan and progress
       - Answer questions and create forums
       - Foster new work relationships needed
  2. Pass out Post-it notes to team members
  3. Ask team members to write two or more items for each easel sheet on change and place on sheets
  4. As a group discuss notes and determine how to address / handle items



WIIFM

- **What:**
  - Help define potential benefits which will help answer question – “What’s In It For Me? (WIIFM)?”
  - Help people understand why they should do something or commit to a change – How is this going to help me, my team or my organization?
- **Why:**
  - Best used proactively to identify potential benefits for key stakeholders
  - Links customers and their requirements
  - Gets away from big picture to personal reason
  - Most are after same goal, discover why disagree and find positive link
  - Part of communication plan
  - Use with Stakeholders Analysis while determining influence strategy for gaps
- **When:**
  - During any phase
    - **Define**: recruiting people for team
    - **Measure/Analyze**: explaining why need someone’s help or expertise; getting team engaged in non-confrontational way
    - **Improve**: engaging key stakeholders on change
    - **Control**: implementing control plan
  - **Proactive**: Identify potential benefits ahead of time and communicate early on
  - **Reactive**: If key stakeholder is not engaged, use to identify why they aren’t and what need to do to get them engaged
- **Need:**
  - Large sheets of easel paper
- **How:**
  1. Identify issue/change trying to implement
  2. Identify key stakeholders
  3. Identify potential benefits from the key stakeholders’ perspective



Issue:______________________________

Target Audience	Potential Benefits (“What’s the benefit to me, my team, my organization?”)
Others who will be affected by project(s)	

Appendix 8 – Keyboard Shortcuts

A variety of keyboard shortcuts exist in the software applications. The following are some of the more common shortcuts.

Windows

Use a menu	Alt-underlined letter
Move from application to application	Alt-Tab
Move from application to application in reverse order	Shift-Alt-Tab
Navigate one character at a time	Arrow
Navigate one word at a time	Ctrl-Arrow (L or R)
Navigate one paragraph at a time	Ctrl-Arrow (Up or Down)
Select while navigating	Shift
Move to beginning of line	Home
Move to end of line	End
Open the Start menu	Ctrl-Esc
Close application	Alt-F4
Close document	Ctrl-F4
Edit a filename	F2
Copy screen	PrintScreen
Copy dialog box	Alt-PrintScreen

Most Applications

New document	Ctrl-N
Open document	Ctrl-O
Save	Ctrl-S
Print	Ctrl-P
Cut	Ctrl-X
Copy	Ctrl-C
Paste	Ctrl-V
Bold	Ctrl-B
Italics	Ctrl-I
Underline	Ctrl-U
Find	Ctrl-F
Replace	Ctrl-H
Find again	Ctrl-G
Undo	Ctrl-Z
Redo	Ctrl-Y
Help	F1

Minitab

Session Window	Ctrl-M
Data Window	Ctrl-D
Edit last dialog box	Ctrl-E
Move from window to window	Ctrl-Tab
Reset dialog box	F3
Maximize a window	Alt-minus, X
Data Window	
Top of column	Home
Bottom of column	End
Up a screen	PageUp
Down a screen	PageDown
Beginning of worksheet	Ctrl-Home
Last column, bottom-most row of worksheet	Ctrl-End
Current row in leftmost visible column	Ctrl-PageUp
Current row in rightmost visible column	Ctrl-PageDown
Session Window	
Beginning of line	Home
End of line	End
Up a screen	PageUp
Down a screen	PageDown
Top of session window	Ctrl-Home
Bottom of session window	Ctrl-End
Select columns	Alt-Drag

Word

Beginning of line	Home
End of line	End
Up a screen	PageUp
Down a screen	PageDown
Beginning of document	Ctrl-Home
End of document	Ctrl-End
Left justify a paragraph	Ctrl-L
Right justify	Ctrl-R
Center justify	Ctrl-E
Justify left and right	Ctrl-J
Increase font size	Ctrl-Shift->
Decrease font size	Ctrl-Shift-<
Superscript	Ctrl-Shift-+
Subscript	Ctrl-Shift-=
Repeat last action	F4
Spell-check	F7
Thesaurus	Shift-F7
Select columns	Alt-Drag

PowerPoint

Insert new slide	Ctrl-M
Move from presentation to presentation	Ctrl-Tab
Go to next slide (normal or presentation mode)	PageDown
Go to previous slide (normal or presentation mode)	PageUp
Move between panes (outline, slide, notes)	F6
Left justify a paragraph	Ctrl-L
Right justify	Ctrl-R
Center justify	Ctrl-E
Justify left and right	Ctrl-J
Increase font size	Ctrl-Shift->
Decrease font size	Ctrl-Shift-<
Superscript	Ctrl-Shift-+
Subscript	Ctrl-Shift-=
Repeat last action	F4
Spell-check	F7
Begin slide show	F5
In slide show mode	
See shortcut keys	F1
Go to beginning of show	Home
Go to end of show	End
Go to particular slide	Slide # - Enter
Black screen	B
White screen	W
In text boxes (Edit mode)	
Beginning of line	Home
End of line	End
Beginning of text object	Ctrl-Home
End of text object	Ctrl-End
Return to Object mode	Esc
In object mode:	
Beginning of presentation	Home
End of presentation	End
Move from object to object on slide	Tab
Select all text in selected object	Enter
Deselect object	Esc
Move object	Arrow keys
Move in a straight line	Shift-Drag (no handles)
Duplicate object	Ctrl-Drag (no handles)
Shrink or expand from center	Ctrl-Drag (handles)
Shrink or expand proportionally	Shift drag (handles)

Excel

Format cells	Ctrl-1
Move from document to document	Ctrl-Tab
Beginning of line	Home
Beginning of document	Ctrl-Home
Bottom-right cell in worksheet	Ctrl-End
Next tab	Ctrl-PageDown
Previous tab	Ctrl-PageUp
Up a screen	PageUp
Down a screen	PageDown
Up a cell	Up Arrow
Down a cell	Down Arrow
Next cell right	Right Arrow
Next cell left	Left Arrow
Topmost contiguous cell	Ctrl-Up Arrow
Bottommost contiguous cell	Ctrl-Down Arrow
Leftmost contiguous cell	Ctrl-Left Arrow
Rightmost contguous cell	Ctrl-Right Arrow
Calculate now	F9
Repeat the last action	F4
Enter and exit Edit mode	F2
Edit mode:	
Beginning of line in cell	Home
End of line in cell	End
Beginning of cell	Ctrl-Home
End of cell	Ctrl-End
Cycle fixed cell references ($)	F4

Lotus Notes

New memo	Ctrl-M
Move from window to window	Ctrl-Tab
Check for new mail	F9
Actions in horizontal or vertical tool bars	Alt- appropriate keys

NetMeeting

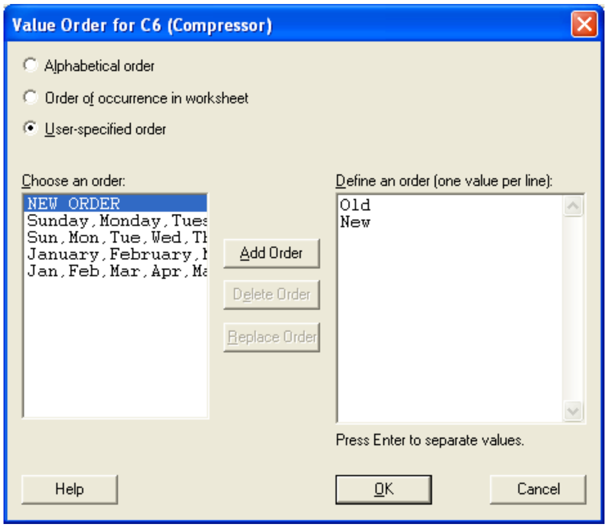
Full-screen mode (toggle)	Alt-Enter
Refresh directory	F5
Open Sharing window	Ctrl-S

Appendix 9 – Changing the Order of Categories/Groups in Minitab Graphs

By default Minitab displays text data in graphs in alphabetical order. To change the order of text categories/groups in Minitab graphs (this does not change the order of the categories/groups in the Minitab worksheet) complete the following steps:

In Minitab:

1. Go to the Minitab worksheet and select the column with the categories/groups.
2. *Editor>Column>Value Order* (you can also get there with a right-mouse click).
3. Choose *User-Specified Order*.
4. If you find a convenient order in the left panel, you can choose it. Otherwise, simply cut and paste the values in the right panel so that they appear in the order you wish.
5. If you have set graphs to automatically update, they will update to the new order. If not, you'll see a yellow symbol in the left title bar of the graph. Do a right-mouse on it and you can update the graph that way.



Value Order for C6 (Compressor)

○ Alphabetical order
○ Order of occurrence in worksheet
● User-specified order

Choose an order:

NEW ORDER
Sunday,Monday,Tues
Sun,Mon,Tue,Wed,Th
January,February,M
Jan,Feb,Mar,Apr,Ma

Define an order (one value per line):

Old
New

Press Enter to separate values.