Leading processes to lead companies: Lean Six Sigma

Gabriele Arcidiacono · Claudio Calabrese · Kai Yang

Leading processes to lead companies:

Lean Six Sigma

Kaizen Leader & Green Belt Handbook

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Gabriele Arcidiacono
Marconi University of Rome (Italy)

Claudio Calabrese
Lean Six Sigma Expert

Kai Yang
Wayne State University, Detroit (USA)

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Foreword

How and why should you become “Green Belt”?

It is not easy to explain *how* with just a foreword, but this book - which is very *lean* and well done - certainly represents the ideal tool to find the right answer to this question.

In my opinion, however, the book is even more effective for those people who are asking themselves “why should I become Green Belt?” I may try to give my personal contribution to this second question.

One possible answer may be: *because my Company has decided that I have to, in order to embark on process of in-house business im-provements.*

Foreword

Apparently this is the least appropriate answer, but it is not true. As a matter of fact, the value you acquire by entering into the training mechanism, by managing an improvement project following the proposed methodology, completing it and, finally, getting the Green Belt Certificate, makes appropriate even this answer.

However, we may provide several answers to the fatidic question and we may consider valid each of them, but most probably, the most appropriate one shall be *because I believe in the Lean Six Sigma methodology and in my professional growth!*

When you work with three inseparable elements like Products, Processes, People, we may surely consider the Process as the one which may positively influence the other two.

Foreword

Better and suitable processes help people professional growth, complete their skills profile and support them in providing better products and services.

Nearby, however, I have my own and personal answer which I believe may complete the one I have already considered as the most appropriate: *I've become Green Belt because I have so strongly believed in this methodology to persuade my company to join it. I've found out both efficiency and effectiveness of the method, but above all, I've deeply needed it. I was needing to wholly lead the processes and to speak the same language of a team of people and, therefore, of a whole company which began to run at higher speed: the results were right there.*

Foreword

And so, thanks to the authors because, coming at the end of this handbook, I am sure that the reader, the manager and the professional will find an obvious and easy answer to a simple question: Why have I become a Green Belt?

Rome, October 2011

Massimo Scaccabarozzi
(Certified Green Belt, Chairman of Farmindustria,
CEO of Janssen Pharmaceutical Company of Johnson & Johnson)

Preface

This Minibook is a brief guide for Green Belt during a Lean Six Sigma project management or for Kaizen Leader during a process improvement activity. Having theoretical concepts and practical examples, it is a handbook for a quick consultancy.
The authors' idea comes from companies' needs to analyze useful information and get to know different kinds of processes in depth.

The set of Six Sigma tools are explained through Minitab 16, the latest release of the most widely used statistical software.

The Authors

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Introduction: Six Sigma

Six Sigma (G) is a proven business strategy (structured according to the DMAIC phases) to measure, analyze and improve the performance in terms of operational excellence.

The methodology, thanks to a wide range of qualitative and quantitative tools, aims to optimize the manufacturing and transactional processes through reduction of their variability.

The 5 stages in the DMAIC approach are:

- DEFINE
- MEASURE
- ANALYZE
- IMPROVE
- CONTROL

(G) *This symbol indicates that the word is included in the Glossary (page 325)*

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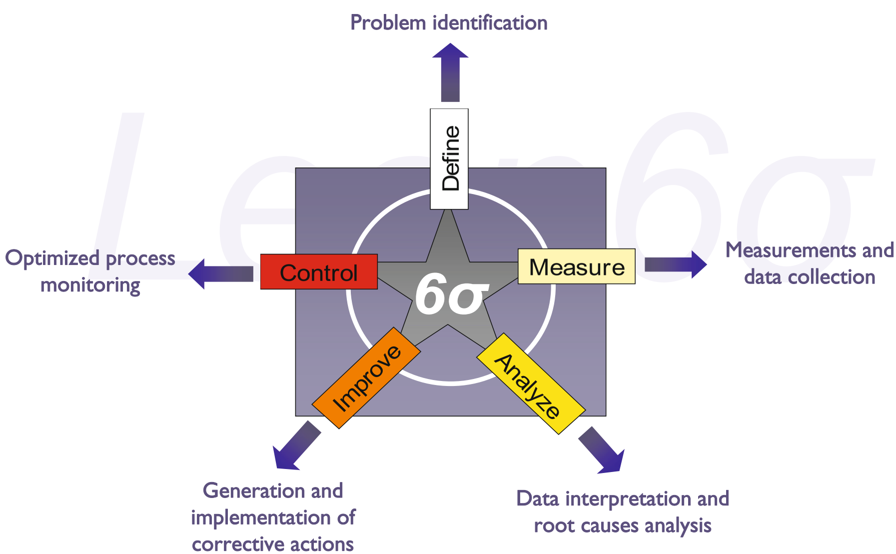
Introduction: DMAIC approach



Introduction: *Lean methodology*

Lean (G) methodology aims to relentlessly identify and eliminate waste in order to maximize speed and flexibility of business processes in order to deliver what is needed, when needed and in the quantity needed by the Customer.

Terms like *Lean Manufacturing* or *Lean Production* are deliberately not used, as the *Lean* method can be widely used in a variety of processes such as production processes and transactional processes, for example:

- ***Lean Production*** or ***Manufacturing*** for production processes
- ***Lean Office*** for service/support processes
- ***Lean Design*** inside the Research & Development process

Introduction to "Waste"

What is the meaning of "**waste**"(G)?

It is the use of resources (time, material, labor, etc.) for doing something that customers are not willing to pay for, and so it does not add value to the product or service provided.

Eliminating waste improves the value of products and services.

The Lean "philosophy" highlights 8 macro-categories of waste:

- Overproduction
- Defects
- Transportation
- Inventory
- Waiting
- Over-processing
- Motion
- Underutilized people

The 8 Wastes

Waste Category	Description	Root Causes	Goals
Overproduction	Overproduction happens when a process produces more products/services than necessary	• Batch Production • Production on forecast	Produce just the necessary, in the right time at the right quality
Defects	Production of defective parts/services that can't be sold to the Customer. Defects can be scraps or reworks, which add tremendous costs to organizations	• Lack of standardization • Lack of training • Lack of error proofing system • Poor quality of supply • Obsolete process	Produce "right first time" Stop the process when the defect occurs, solve the problem in order to remove it definitively
Transportation	Unnecessary transport of materials	• Batch Production • Inefficient layout • Long set-up time	Minimize the movement by arranging processes in close proximity to each other
Inventory	Too many finished goods in inventory, WIP inventory, raw material inventory	• Batch Production • Long set-up time • Bottleneck • Lack of continuous flow • Push organization	The inventory must be dimensioned based on the real actual usage and on the supplier delivery time
Waiting	Customer waiting, waiting for materials, waiting for employees	• Bottleneck • Lack of continuous flow • Lack of standardization • Unbalanced workload	Maximize "value adding" time to reduce waiting and to arrange processes in a continuous flow approach
Over-processing	Unnecessary processes or operations	• Not Value Added activity • Lack of investigation of Customer needs • Activity by "tradition"	Optimize Value Added activities to remove all the unnecessary steps
Motion	Not Value Added movement of people and machines	• Inefficient layout and process flow • Lack of standardization	Remove unnecessary motion and improve disposition of material in the workplace
Underutilized People	Not using people's skills, people are seen as a source of labor and are not involved in finding solutions/opportunities to improve processes	• Lack of involvement • Old Culture	People are the most important resource in a company: let's involve them as much as possible in company activities

Introduction: *Lean Thinking approach*

Every time a Lean expert looks at a process optimization he/she must consider the 5 *Lean Thinking* principles:

1° LEAN PRINCIPLE ***Value***
Identify the value of the product/service and process from Customer's point of view

2° LEAN PRINCIPLE ***Value Stream***
Map the process value stream to discover and understand what is value for the Customer

3° LEAN PRINCIPLE ***Flow***
Value added processes must be arranged in a continuous flow without delays and interruptions, so *Lead Time* is reduced (ideal situation "one piece flow")

4° LEAN PRINCIPLE ***Pull***
Produce to Customer demand (the right product, in the right time and in the right quantity)

5° LEAN PRINCIPLE ***Perfection***
Move from a reactive point of view to a "proactive" one, to establish a continuous improvement process of performance (looking for new Customer expectations and new possibilities to eliminate waste)

Introduction: *Kaizen Event approach*

Objective:

- KAIZEN[(G)] means "to become good through change". A Kaizen event is a focused effort to improve activity. A multi-functional team is created and, for a period of 3-5 days, focuses on resolving a specific problem. The main objectives of a Kaizen event are to solve problems and/or eliminate "waste"

When to use it:

- Kaizen events are mostly used to develop activity such as:
  - 5S
  - Standard Work
  - Changeover Reduction (SMED)
  - Kanban implementation
  - Flow Improvement
  - Cell Design
  - Problem solving activities
  - TPM & OEE implementation

Lean6σ

Introduction: *Kaizen Event approach*

1. BEFORE KAIZEN EVENTS

IDENTIFY OPPORTUNITY

The activity should be linked to one or more company goals

SET THE TARGET

Identify the goal of the event; for example:
- Space reduction
- Inventory reduction
- Cycle time reduction
- Productivity
- Customer Satisfaction

KAIZEN TEAM

Identify the team (typically 5-8 people); for example:
- Kaizen Leader and Co-Leader
- Manufacturing Engineer
- Product Engineer
- Material Planner
- Safety
- Quality Specialist

2. DURING KAIZEN EVENTS (3-5 days)

INITIAL TRAINING

The initial training aims to introduce the activity for the next 3-5 days and must not be longer than 2 hours

CURRENT STATE ANALYSIS

Data collection, problem description, Process Mapping, Current State performance definition

FUTURE STATE ANALYSIS

Identify improvements, reduce or eliminate waste, describe Future State, implement actions

RUN THE NEW PROCESS

Test the action implemented, new data collection and results analysis

ACTION PLAN & CLOSURE

Action plan of open points to be implemented (Kaizen Newspaper), prepare presentation for Kaizen Event, closure activity

3. AFTER KAIZEN EVENTS

ACTION PLAN IMPLEMENTATION

Kaizen Newspaper implementation

NEW PROCESS CONSOLIDATION

Standardize process measurements

STANDARDIZATION OF NEW PROCESS

Control plan of process measurements

EXTENTION OF THE RESULTS IN NEW AREAS

Identify opportunity to deploy the results on similar areas

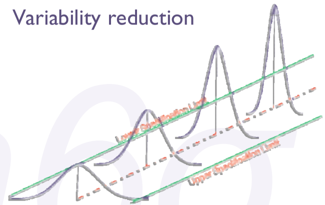
Introduction: Kaizen Events vs LSS Project

Elements of comparison	Lean Six Sigma Project	Kaizen Events
Scope	Wide	Circumscribed
Duration	3-5 months	3-5 days (depending on Kaizen Event)
Training	Lean Six Sigma Training (Black Belt; Green Belt or Yellow Belt)	Kaizen specific training, on the job training
Team	Multifunctional Team	Multifunctional Team (or sometimes natural teams)
Team size	Depending on project	5-8 people
Depth of analysis	Generally high	Generally low
Involvement	Part time involvement	Full time involvement

The power of *Lean Six Sigma*

LEAN PURPOSE:
Speed and flexibility through waste identification and elimination

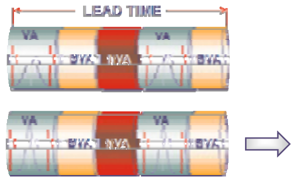
SIX SIGMA PURPOSE:
Variability reduction



LEAN SIX SIGMA APPROACH

Not value added activities reduction/elimination

Variability reduction



The final process is "fast" and "capable"

DEFINE

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DEFINE

Define phase is the first *step* of a *Lean Six Sigma* project and therefore it is necessary to determine:

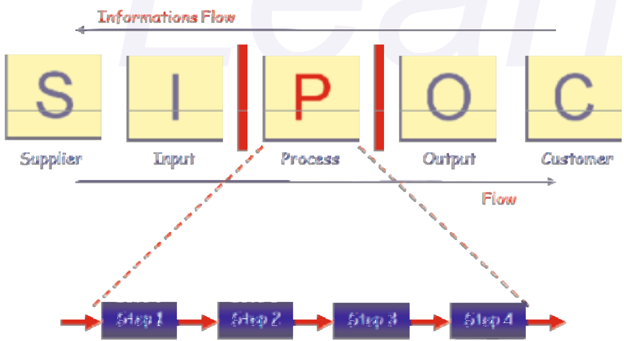
- the snapshot of the process through mapping (identifying value added activities and not value added activities)
- the Customer (external or internal)
- weakness and critical points of process
- the scope of the project and therefore the *ring* of intervention
- a measureable indicator from Customer point of view, called *Critical To Quality* (CTQ(G)), and customer satisfaction analysis through a proactive approach instead of reactive
- an estimation of potential benefit (economic and/or strategic, written inside the summary document called *Project Charter* (G)), achievable thanks to the implementation of improvements planned during project development

SIPOC Diagram

Objective:

- SIPOC[(G)] Diagram maps the process from a macroscopic point of view. It should be used during the early stages of an improvement project in order to capture sufficient detail to be able to manage the process

Overview:



S = *Supplier*

I = *Input*, X Variable

P = *Process*, Macro-level

O = *Output*, Y Variable

C = *Customer*

SIPOC Diagram

The six steps to construct SIPOC:

1. Identify *Customers* (G) (external and/or internal)
2. Identify process *Outputs*
3. Locate Macro-process boundaries (start and end of process)
4. Determine *Process Owner* (G)
5. Define process *Inputs* and *Relative Suppliers*
6. Repeat the procedure using a "TOP-DOWN" approach (start from the macroprocess to reach more detailed analysis). During the process mapping, distinguish value added phases (VA) from not value added ones (NVA) (see page 19)

SIPOC Diagram

Useful questions during SIPOC construction:

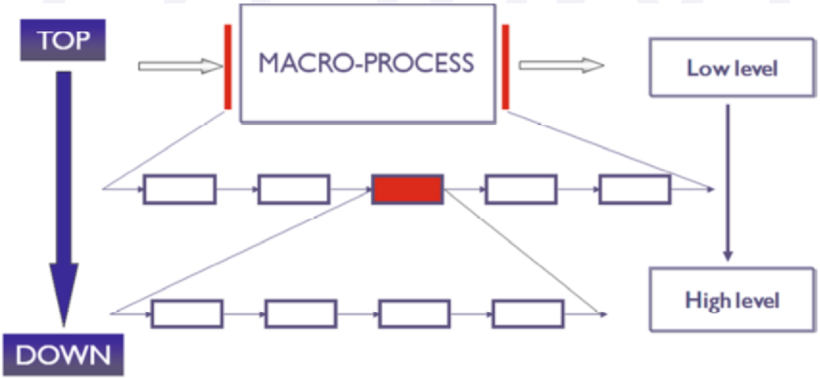
- Who is the *Customer*?
- Is the *Customer* inside or outside the company?
- What does the *Customer* need from the process?
- What are the *Outputs* of the process?
- Where does the examined *Process* start and end (project *ring*)?
- Does the process describe the "as-is" situation or the process desired?
- What are the *Inputs*? What are the specifications agreed upon in terms of *Inputs* with *Suppliers*?
- Who are the *Suppliers*?

Process Mapping

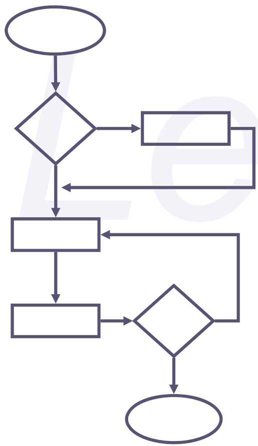
Objective:

- The process mapping will describe, at a high level, the analyzed process to identify critical points, both value added and not value added activities

Overview:

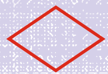


Process Mapping: Basic flow diagram

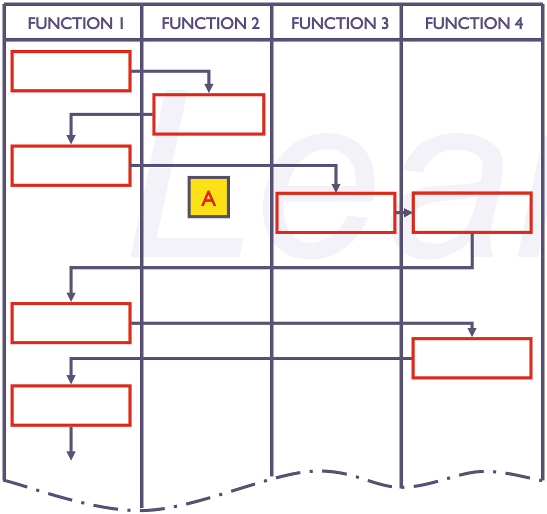


Objective:

- identify the main steps of a process: starting and final points
- identify the decision-making cycles in the process

ICONS FOR REPRESENTATION	
	Question mark
	Direction of logical flow
	Input/Output
	Process phase
	Start/Finish of process

Process Mapping: Functional flow diagram



Objective:

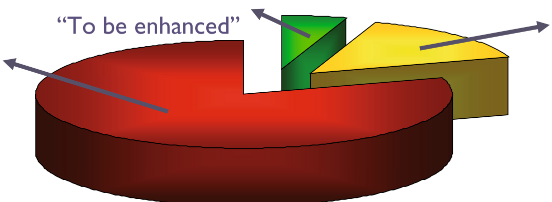
- to highlight links among departments/functions in a process flow
- clarify the roles and responsibilities

A

The horizontal line represents the transfer of functional responsibility

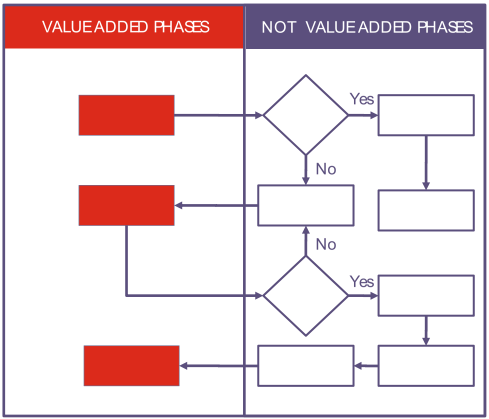
Value Added and Not Value Added

- In a process it is possible to identify three main kinds of activities:
  - Value Added Activity (VA(G)):
    - Activity that increases the value of the product/service from the customer's point of view
    - Something that the customer is willing to pay for
  - Not Value Added Activity (NVA(G)):
    - Activity that does not add any value to the product/service
  - Business Value Added Activity (BVA(G)):
    - Activity that does not add any value to the product/service but is necessary from a business operations' point of view



Example of a company process

Process Mapping: Activity flow diagram



Objective:

- to visualize process complexity
- to identify decisional cycles and bottlenecks
- to determine Not Value Added phase for product/service (waste[(G)])

Value added phase (VA)

- Customer willing to pay for it
- Step that physically transforms the product/service
- Phase that produces *right first time* product/service

Not value added phase (NVA)

- Non essential phases for output production:
  - Defects, reworks
  - Testing
  - Checking
  - Transporting, motion, waiting
  - Overproduction, Inventory

Waste Walk

Objective:

- The Waste Walk aims to consider the flow of a product / service from start to finish (Example from raw materials to finished goods) and highlights all forms of waste along the way

When to use it:

- The method is very useful to highlight the macro-waste in a process and then to start an improvement action plan with low investment and high return activities on the business processes

Waste Walk: operative procedure

How to perform a "waste walk":

1. Select a product/service provided
2. Go through the end-to-end process following the product and pay attention to detail
3. Identify the waste referring to the eight categories of Lean methodology
4. Collect on a piece of paper all the information related to the waste detected
5. If possible, try to quantify the entity of the waste (€, time, resources, etc.)
6. Clearly describe how wastes are created in the process
7. Generate possible ideas for waste elimination or reduction

Waste Walk: operative procedure

Example of a format for collection of necessary information during a Waste Walk analysis:

"Waste Walk Format"

Company: ____________ Product/Practice followed: ____________

Observer: ____________ Date: ____________

Waste category	Process Step	Waste Comment	Waste estimation	Possible idea/solution
Insert the waste category identified	Insert the process step where the waste has been identified	Waste description	Try to insert, if it's possible, an estimation of waste entity	Generate one or more ideas for waste reduction/elimination

Waste Walk: operative procedure

Example of data collection:

"Waste Walk Format"

Company: XXX — Analyzed Product: Az345

Observer: Mr. Yellow — Date: November 20, 2008

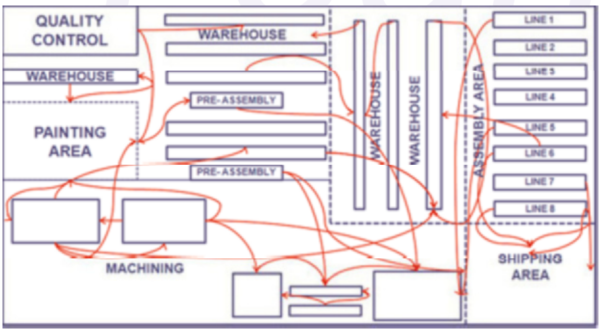
Waste category	Process Step	Waste Comment	Waste estimation	Possible idea/solution
Inventory	Heat treatment	Inventory of treated materials out off the shelves	14 pallets	Batch size reduction
Waiting	Molding	The process is waiting material from machining processes	10 minutes per hour, 2 operators	
Scraps	Assembly	10% of the parts do not pass the final inspection and need a rework process	10% of 4000 parts x 6 mins = 2400 mins	
Motion	Final assembly	The test station is located 10 meters away from the workplace, workers take 30 seconds to go and come back every time a test is done	30 secs x 1,100 parts per days = 550 mins	Move the location of the test area
Inventory	Final assembly	Too many pallets are waiting for the box closure because of lack of additional elements	19 pallets	Assemble components only when all objects are present

Spaghetti Diagram

Objective:

- The Spaghetti Diagram is a visual description of actual flows (usually material and/or people flows). It is an effective tool to see the shortcomings in a process such as excessive material movements, long walking distances and layouts that are not designed based on actual process needs

Overview:

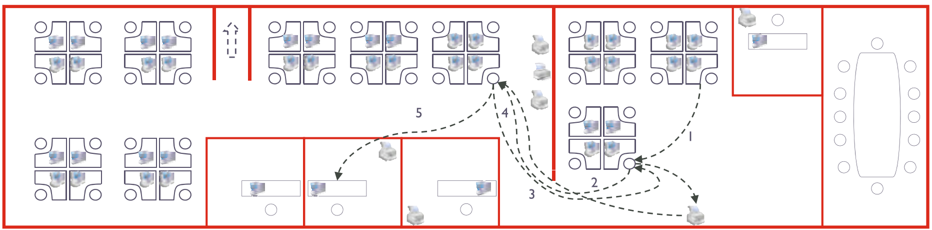


Spaghetti Diagram

How to build a Spaghetti Diagram:

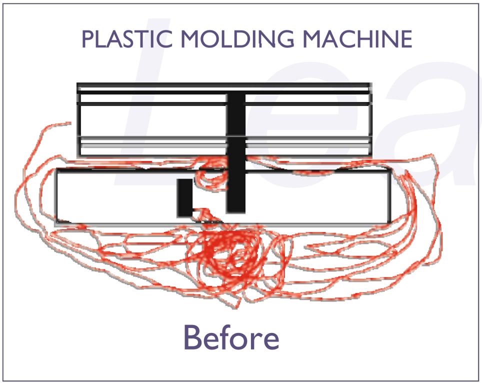
1. Identify the product, file, information, person and material to follow through
2. Take a pen and the facility layout, drawn on paper (or layout of the area in question)
3. Follow the product, information and people flow step by step and draw the actual movement paths on a piece of paper and measure the path distances

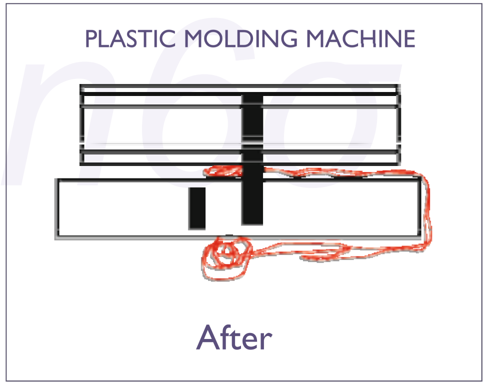
Example of a file managed through a service company process



Spaghetti Diagram

Example of Spaghetti Diagram before and after an optimization activity on Set-Up process (SMED – Single Minute Exchange of Die)





Product Family Matrix

Objective:

- Product Family Matrix is a tool used to group many products into the "product family". The product will belong to a family if the processes or components necessary to produce it are similar to those of other products in that family

When to use it:

- The tool is used before performing a value stream analysis. When product variety is low, it is possible to have one Value Stream Map for each kind of product. However, in most companies there are hundreds of products and it is impossible to draw hundreds of Value Stream Maps. In this case it is useful to group products into "families"

Product Family Matrix

How to build a Product Family Matrix:

1. Place different kinds of product line by line
2. Place processes or components according to product type in columns (pay attention to the downstream processes that generally differentiate the product)
3. For each product, highlight the processes or components used
4. Identify the "Product Family" by degree of similarity in columns used

Overview:

	PROCESS STEP / DEPARTMENT / EQUIPMENT / COMPONENT												
	1	2	3	4	5	6	7	8	9	10	11	12	13
PRODUCT A	X	X	X			X	X	X		X	X		
PRODUCT B	X	X	X			X	X	X	X	X	X		
PRODUCT C	X	X	X	X		X	X	X		X	X		
PRODUCT D			X	X	X			X	X	X		X	X
PRODUCT E			X	X			X	X	X			X	X
PRODUCT F			X	X	X			X	X	X	X	X	X
PRODUCT G	X		X			X	X				X	X	X
PRODUCT H	X		X			X	X				X	X	X

Family A (Products A, B, C)
Family B (Products D, E, F)
Family C (Products G, H)

Don't spend a lot of time in Product Family Matrix construction; it is not a value added activity for the customer

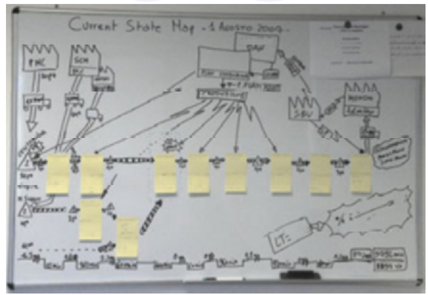
It is advisable to build up a Value Stream Mapping for each family, starting from the biggest family in terms of quantity sold to the customer

Value Stream Mapping (VSM)

Objective:

- Value Stream Mapping (VSM[G]) is a diagram of every step involved in the material and information flow necessary to bring the product/service from the order to delivery phase. Value Stream Mapping is a very good starting point to identify opportunities for improvements

Overview:



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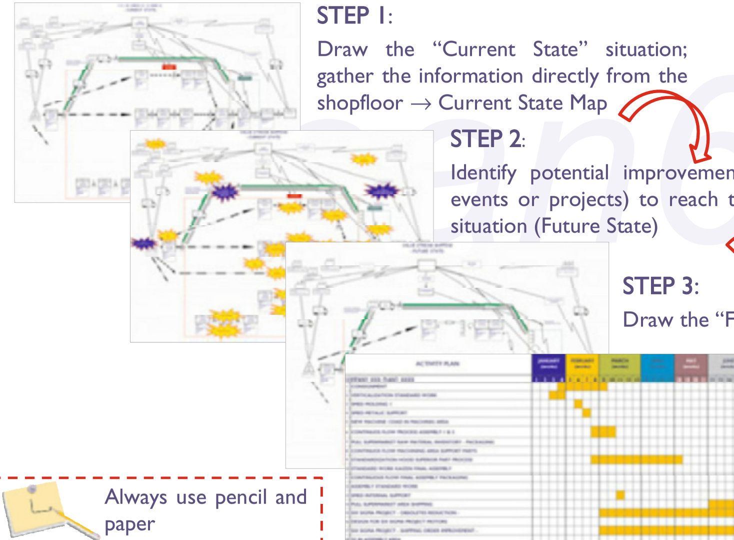
Value Stream Mapping (VSM): Roadmap

How to perform a Value Stream analysis:



STEP 1:

Draw the "Current State" situation; gather the information directly from the shopfloor → Current State Map

STEP 2:

Identify potential improvements (Kaizen events or projects) to reach the desired situation (Future State)

STEP 3:

Draw the "Future State Map"

STEP 4:

Build an action plan to pass from the Current State to the Future State situation (Value Stream Plan)

Always use pencil and paper

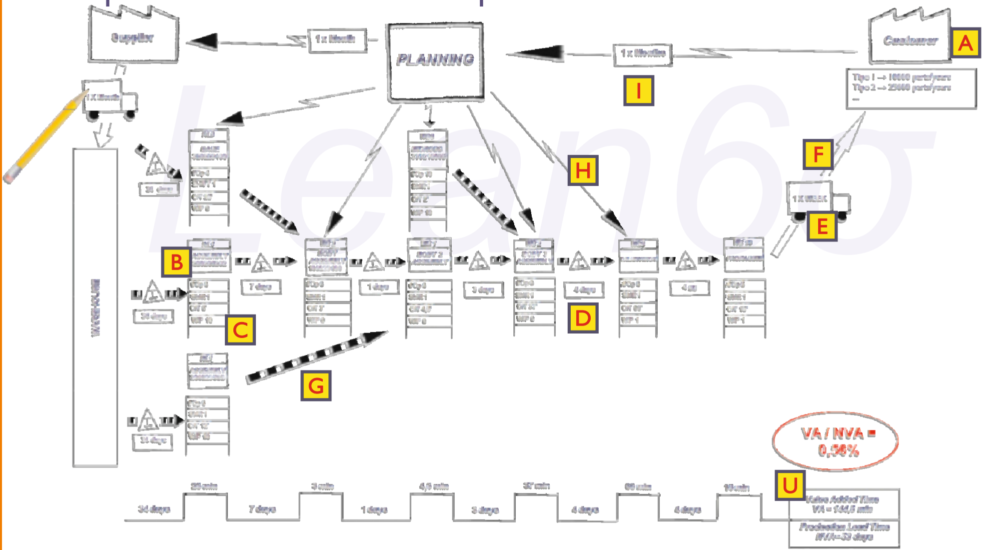
Value Stream Mapping (VSM): Current State

Guidelines to build a Value Stream Map:

1. Identify the product family to analyze (use, if necessary, the Product Family Matrix)
2. Go to the shopfloor and begin mapping, starting from the customer, and go back upstream through the entire flow. Describe step by step processes and gather information such as:
   - Customer information
   - Intermediate inventories and their location
   - How the information flow runs inside the company
   - Production input of the single process
   - Process Cycle Time, Set-Up time, Number of operators for each step, WIP
   - Lead Time(G)
   - Supplier information

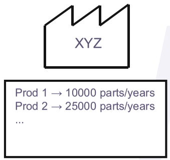
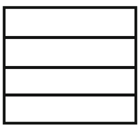
Value Stream Mapping (VSM): Current State

Example of a Current State Map:

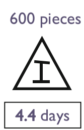
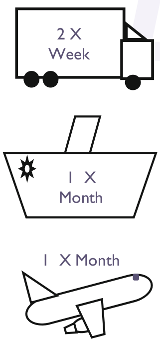


Value Stream Mapping: Standard Icons

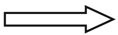
These icons are the common language to do the Value Stream Analysis

ICON	NAME	DESCRIPTION	PRACTICAL NOTES
	Customers/Suppliers (page 33) A	Use to show Customers, Suppliers and External processes. Place in the top right/left corner of the diagram	Gather information such as: •Customer/Supplier Name •Customer/Supplier location (Europe, USA etc.) •Number of products required •Mix of products •Batch size/delivery lead time (supplier)
	Process Step B	Use to show a process, (exclude elementary work tasks)	Identify Process Name Identify kind of process
	Data Box C	Use to show all important information concerning each process/customer/supplier. This is generally placed under each process	Example of information for a process: • No. of Operators (VSM icon) • Cycle Time/Set Up Time/Uptime • No. of Shifts • Batch Size • Wip • % Defects (PPM,DPMO)

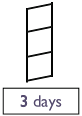
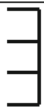
Value Stream Mapping: Standard Icons

ICON	NAME	DESCRIPTION	PRACTICAL NOTES
	Inventory D	Use to show inventory; try to quantify the inventory in terms of parts, inventory value and time	How to calculate time; example: • average Customer requests → **30,000** parts/year • average Customer demand per day → 30000/220 (220 days in 1 year) = **136** parts/day • inventory time: 600/136= **4.4 days**
	Shipment Method E	Use to identify kind of shipment	Identify: • shipment method (truck; airplane; ship) • delivery frequency • date of shipment

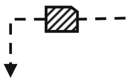
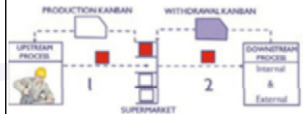
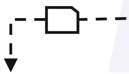
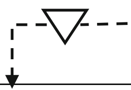
Value Stream Mapping: Standard Icons

ICON	NAME	DESCRIPTION	PRACTICAL NOTES
	External transportation F	Movement of finished goods to the customer or movement from supplier to the company	This icon is used if a supplier is involved during the production cycle
	Movement of material in push logic G	Material is produced and moved to the next step process when not needed	This happens when production is based on schedule but not on Customer demand
	Electronic Information H	Communication between processes in an electronic flow	Example: • IT system information
	Manual information	Use to describe a manual information flow	Example: • production schedule • delivery schedule
Weekly Schedule	Information I	Use to identify information	Identify the frequency of the information

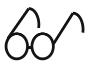
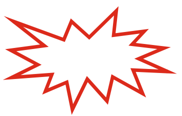
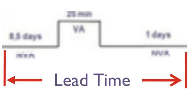
Value Stream Mapping: Standard Icons

ICON	NAME	DESCRIPTION	PRACTICAL NOTES
	Buffer or safety stock	Used to indicate the buffer/safety stock	The level of buffer stock must be measured (in days or number of parts) under the icon
	Supermarket L	A controlled inventory of parts that "pull" the production from an upstream process	Replenishment is based on actual consumption of stock. If the supermarket is not used, the upstream process doesn't produce any product on supermarket (Pull System)
	Withdrawal (Pull material) M	Used to represent a pull material	Used usually for a request from a process to a supermarket/warehouse 
	First In First Out Sequence	Used to represent transfer of material between processes in a "FIFO" sequence	The first part that goes into the process is the first part to go out. (Example: Conveyor)

Value Stream Mapping: Standard Icons

ICON	NAME	DESCRIPTION	PRACTICAL NOTES
	Withdrawal Kanban **N**	Used to instruct the material handler to take and transfer parts from a supermarket/inventory to a downstream process	 1 - The upstream process produces what has been consumed from the supermarket 2 - The downstream process withdraws from supermarket what it needs in the right quantity
	Production Kanban **O**	Used to engage the upstream process to produce what is necessary for replenishment of supermarket/inventory	
	Signal Kanban **P**	This signal is used when the reorder point (G) is reached and a new batch must be produced	The "batch kanban" is necessary when supplying process must produce in batches because of Changeovers
	Kanban Post **Q**	Used to show place where Kanban are collected to be taken from material handler to replenish processes	The kanban post could be a mailbox which collects the kanban card or a place which collects bins/balls, etc.

Value Stream Mapping: Standard Icons

ICON	NAME	DESCRIPTION	PRACTICAL NOTES
	Level load production **R**	The icon is used to indicate levelling of production quantity rather than batching	Tool to intercept batches of kanban and levelling the volume and mix over a period of time ("Every part every day")
	Visual Checking and scheduling **S**	Used to highlight a point where the inventory level is checked visually	Gathering of information through visual checks. Visual management is one of the most important and frequent concepts in lean deployment
	Improvement activity **T**	Used to highlight improvement at a specific point of the process stream	To get a global view of what is needed to reach a lean flow. The improvement can be Kaizen Workshop, Six Sigma project, Problem Solving activities, etc.
	Timeline **U**	The timeline shows value added times (Cycle Times) and non-value added times. Use this to calculate Lead Time and Total Cycle Time	The timeline is used to calculate the **Process Cycle Efficiency,** i.e. the ratio between Value-Added Activities and Not Value Added Activities: $PCE = \frac{\Sigma VA}{\Sigma NVA} = \frac{25\ min}{9{,}5\ days} = 0{,}54\%$

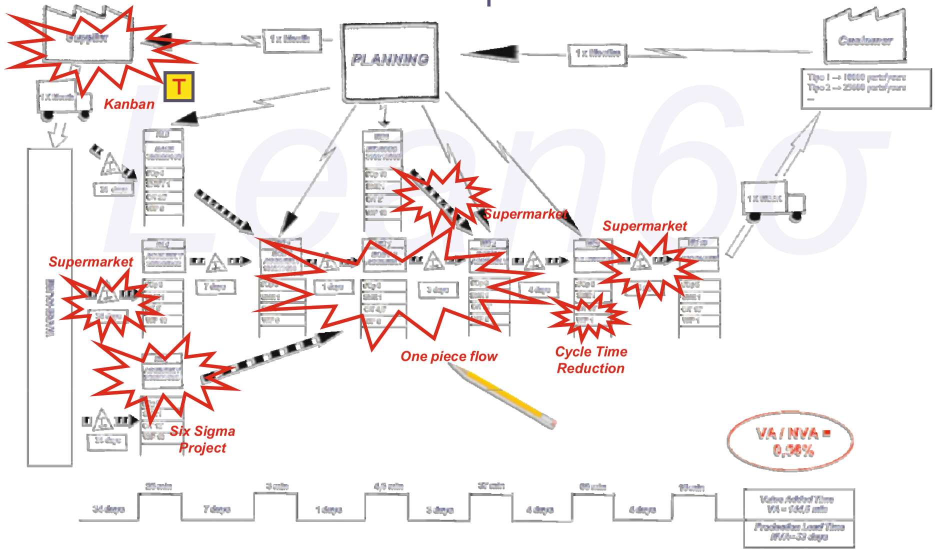
Value Stream Mapping (VSM): Future State

What does "Lean" do in a value stream? Key elements for a good future state map design:

1. Identify and eliminate sources of overproduction
2. Produce product/service with *takt-time* rhythm (identify Takt Time)
3. Create continuous flow, where possible
4. Where a continuous flow is not possible, use pull system for process connection instead of a push system (using supermarket)
5. Reduce batch size and, where possible, introduce the "one piece flow" approach
6. Send the scheduling to the process nearest the Customer (*Pace-Maker* process). Will the customer pull from a finished goods supermarket or directly from shipping?
7. Level mix / volume production at the Pace-Maker process
8. Identify potential improvements for each process step (Change-over, Standard Work, TPM, Variability reduction, Kanban, Cell Design, Problem Solving)

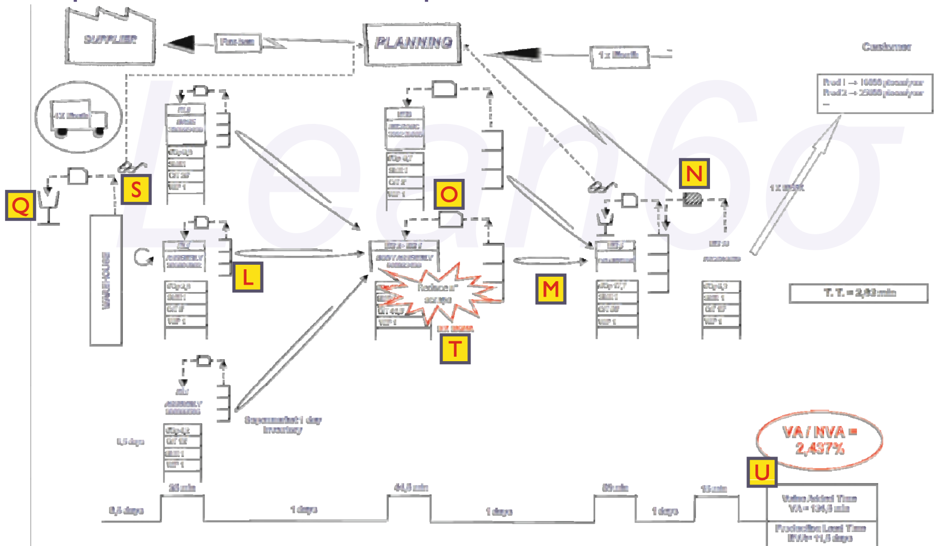
Value Stream Mapping (VSM): Future State

How to reach the Future State Map:



Value Stream Mapping (VSM): Future State

Example of a Future State Map:



Value Stream Mapping (VSM): Future State

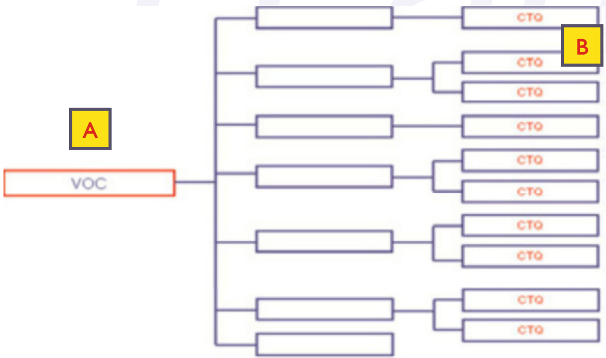
Example of a Value Stream Map:

CTQ-Tree Diagram

Objective:

- Tree Diagram is a tool moving from VOC[G] (*Voice Of the Customer*) to one or more CTQs, translating the customer's voice into objectively measurable indicators.

Overview:



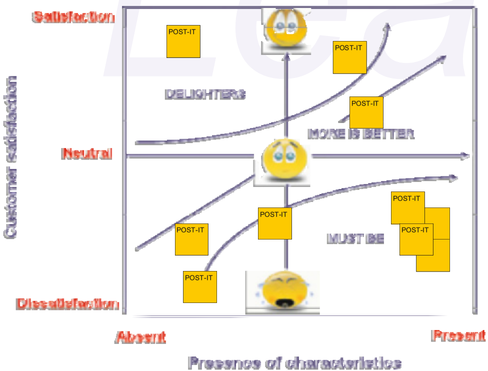
A	Request in customer's language
B	The CTQ expresses customer needs in a clear, unmistakable language that everybody can understand

Kano Diagram

Objective:

- Kano Diagram is a tool that aims to identify the important aspects to drive *Customer Satisfaction* (G)

Overview:



Must Be: Qualities that are present and what customers expect to be present (e.g. product or service must be safe)
More is Better: These qualities are directly correlated to customer satisfaction. The more present they are, the bigger the Customer Satisfaction
Delighters: Qualities unexpectedly found by the Customer and consequently, if present, increase his/her satisfaction

Project Charter

Project Charter			
Title	Reduce the percentage of scrap in the cable assembly lines		
Scope	The project will focus on defect E, G, A, which constitute 75.3% of the total defects examined		
Team Leader	M. White (GB)	Telephone	3481
Team Member	P. Green	Telephone	3456
	S. Yellow	Telephone	3476
	R. Black	Telephone	3454
	C. Blue	Telephone	3410
		Telephone	
Process Owner	F. Violet Production Responsible	Telephone	3400
Champion	F. Orange	Telephone	3289
Duration	4	months	
CTQ	N° Scraps/Pieces produced		
Actual value	12%		
Expected value	2%		
Savings	78.000 €	Euro/year	
Constraints	Do not increase the cycle time		
Milestone	Expected Start	Expected closure	% Progress
Define	08 february	22 march	100%
Measure	22 march	30 april	100%
Analyze	30 april	27 may	100%
Improve	27 may	15 june	100%
Control	15 june	04 july	75%

Project Charter

Contents of Project Charter:

Title	Indicate project title
Scope	Describe in more detail the purpose of the project, in order to better explain the meaning of the title
Team	Insert the people who are involved in the project deployment: – *Team Leader* – *Team Members* – *Process Owner:* Owner of the area (Department/Office) involved in the project – *Champion/Sponsor:* is the financial backer of the project Six Sigma
Duration	Identify project duration (4-5 months)
CTQ	Identify the project CTQ to be analyzed (it could be one or more than one), the current value and the expected value (*target*) at the end of the project
Savings (G)	Insert the value of financial benefits (in terms of revenue and/or cost) that should be achieved when the CTQ target is reached at the end of the project (benefits per year)
Constraints	Identify the constraints which must be respected during the project development
Phases	Highlight the start-up date for each phase, expected closure date and the real percentage of progress (Project Charter is an "ongoing document" and the starting point of all project meetings)

COPQ: Cost Of Poor Quality

- Cost of Poor Quality, called COPQ[G] (*Cost Of Poor Quality*), are those costs due to poor performance of manufacturing and/or transactional processes and include labor costs, energy, materials, depreciation, which must be sustained to avoid generating non-conformity or in response to their occurrence
- A possible model for COPQ could be the following:

COPQ	COSTS OF QUALITY	• Prevention costs • Checking costs
	COSTS OF NON CONFORMITY	• Costs due to internal defects • Costs due to external defects

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COPQ: Cost Of Poor Quality (example)

COPQ	COST OF QUALITY	PREVENTION COSTS	- Preventive maintenance - Process Audit - Product Audit - Process Capability study - Machine Capability study
		CHECKING COSTS	- Checking - Test - Check on invoices - Check on purchase order - Life cycle test on products
	COST OF NON CONFORMITY	COSTS INTERNAL DEFECTS	- Scraps - Reworks - Delays and waiting - Invoices issued late - Wrong sales forecasts - Production stoppages for problems
		COSTS EXTERNAL DEFECTS	- Customer returns - Warranty assistance - Penalties - Downgrade products - Production of documents related to returns

MEASURE

Arcidiacono G., Calabrese C., Yang K.: Leading processes to lead companies: Lean Six Sigma.
DOI 10-1007/978-88-470-2492-2, © Springer-Verlag Italia 2012

MEASURE

Measure phase is the second step of a Lean Six Sigma project, where:

- a "rational" data collection is performed for the scope chosen: this collection requires effective and efficient planning in order to create a database of knowledge to record the process which will highlight the critical issues from an objective standpoint
- the data is interpreted through statistical tools (in case of samples, to test their significance and how they are seen/shown over-viewed)
- the reliability of data is verified
- process performance is calculated through the proper KPI (OEE, Takt Time, Process Sigma, Process Capability etc.)

Sampling

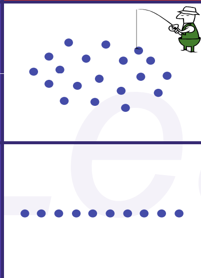
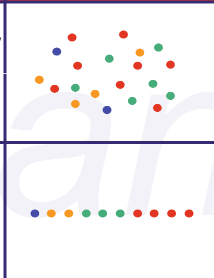
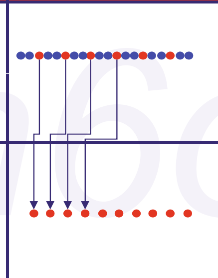
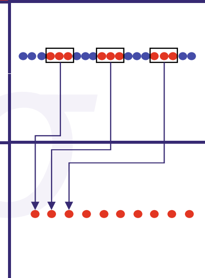
Objective:

- Gather a subset of data (n) representative of the population (N)

When to use it:

- When the observation of all data (population) would:
  - require too many financial resources
  - take longer than the time at one's disposition
  - "destroy" the entire population (e.g. in case of destructive tests)

Sampling

Sampling strategy	Random Sampling	Stratified Random Sampling	Systematic Sampling	Subgroups Sampling
Process configuration (population)				
Sample				
Description	Each element has an equal chance of being selected	The sample respects the population proportions	Each sample unit is collected every "m" units	X units are selected at equally spaced intervals of time (seconds, minutes, hours, etc.)

Sampling

Sample size calculation to estimate the population's mean (formula for continuous data):

$$n = \left(\frac{2s}{d}\right)^2$$ Formula (i)

where:

- n = Sample size
- s = Standard deviation or its estimate
- 2 = factor corresponding to a Confidence Interval of 95% (the exact value is 1.96)
- d = Precision required in mean estimation

Sampling

Sample size calculation for the estimation of the population proportion (formula for discrete data):

$$n = \left(\frac{2}{d}\right)^2 (p)(1-p)$$ Formula (ii)

where:

- n = Sample size
- p = Proportion estimation (if it is not known use p = 0.50)
- 2 = factor corresponding to a Confidence Interval of 95% (the exact value is 1.96)
- d = Precision required in proportion estimation

Sampling

- Formulas (i) and (ii) are valid if the sample size is less than 5% in comparison with population size

$$\frac{n}{N} < 0.05$$

- If the sample size is more than 5% of the size of the population, it is possible to adjust the sample size obtained with (i) and (ii) using the formula below:

$$n_{correct} = \frac{n}{1 + n/N}$$

CORRECTIVE FORMULA

Basic Statistics

Objective:

- Represent the main statistical properties of a set of data (sample or population)

Characteristics:

- Location parameters
  - Mean, Mode, Median, Quartiles, Percentiles
- Dispersion parameters
  - Range, Standard Deviation, Variance
- Shape parameters
  - *Skewness, Kurtosis*

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Basic Statistics

Location parameters

The location parameters aim to identify the most frequent values of distributing data

Dispersion parameters

The dispersion parameters can assess the variability of data

Shape parameters

The shape parameters are used to assess whether the data collected are arranged according to a symmetrical distribution

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Basic Statistics

Location parameters:	
Mean	$\overline{X} = \frac{\sum_i X_i}{N}$
Mode	The value, among data, with highest frequency
Median	The value having the characteristic that one half of the values is larger and the other half smaller. The value divides the set of data into two equal parts (it is the mean of the two central values if the number of data is even)
First Quartile (Q_1)	The value of a concept for which three quarters (75%) of the value are larger and one quarter (25%) is smaller
Third Quartile (Q_3)	The value of a concept, thus one quarter (25%) of the value is greater and three quarters (75%) are smaller
Dispersion parameters:	
Range	$Range = x_{\max} - x_{\min}$
Standard Deviation (StDev)	$\sigma = \sqrt{\frac{\sum (X_i - \bar{X})^2}{N-1}}$
Variance	$\sigma^2 = \frac{\sum (X_i - \bar{X})^2}{N-1}$

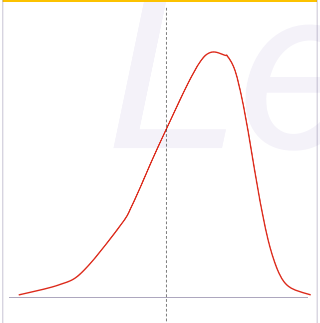
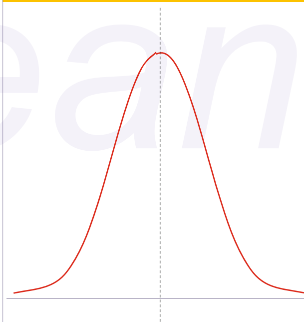
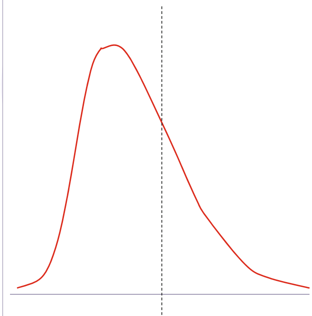
Basic Statistics

Shape parameters:

Measure	Description
Skewness $Skewness = \frac{N}{(N-1)(N-2)}\sum\left[\frac{(x_i-\bar{x})}{s}\right]^3$	The value that measures the asymmetry of distribution: • Skewness < 0: the distribution is shifted to the right • Skewness > 0: the distribution is shifted to the left • Skewness = 0: the distribution is symmetrical
Kurtosis $Kurtosis = \frac{N(N-1)}{(N-1)(N-2)(N-3)}\sum\left[\frac{(x_i-\bar{x})}{s}\right]^4 - \frac{3(N-1)^2}{(N-2)(N-3)}$	The Kurtosis is a measure of how the distribution of the analyzed data differs from a normal distribution: • Kurtosis < 0: the distribution has a softer peak, shoulders are bigger and tails are thinner than a normal distribution • Kurtosis > 0: the distribution has a sharper peak, shoulders are finer, and tails are larger than a normal distribution

Basic Statistics

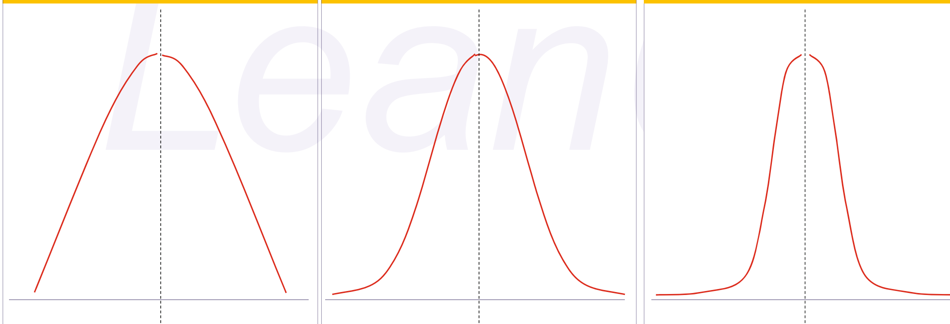
A graphic explanation of the meaning of Skewness, a symmetry parameter, is as follows:

$S < 0$	$S = 0$	$S > 0$
		
Distribution skewed to the right (the mode is shifted to higher values of the distribution)	Symmetrical distribution	Distribution skewed to the left (the mode is shifted to lower values of the distribution)

Basic Statistics

A graphic explanation of the meaning of the Kurtosis, a symmetry parameter, is as follows:

K < 0 | *K = 0* | *K > 0*

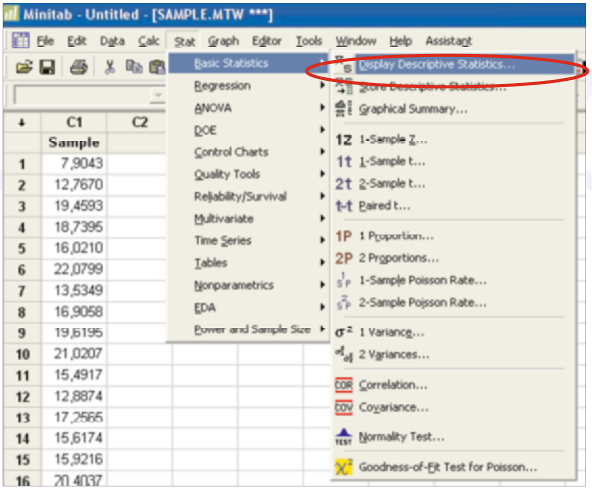


Distribution with "flat" shape | Normal distribution | Distribution with "sharp" shape

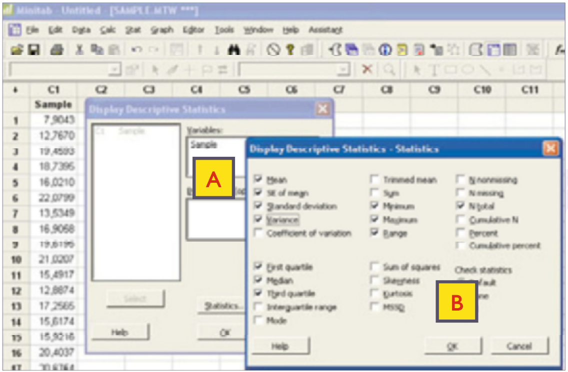
Basic Statistics

MINITAB:

Stat > Basic Statistics > Display Descriptive Statistics…



Basic Statistics



A

Insert the column of the sample to be analyzed in terms of basic statistics

B

Select all parameters of interest

MINITAB Output:

Descriptive Statistics: Sample

Variable	Total Count	Mean	SE Mean	StDev	Variance	Minimum	Q1	Median
Sample	100	16,034	0,282	2,822	7,963	7,632	13,870	16,618

Variable	Q3	Maximum	Range
Sample	17,801	22,080	14,448

Confidence Interval

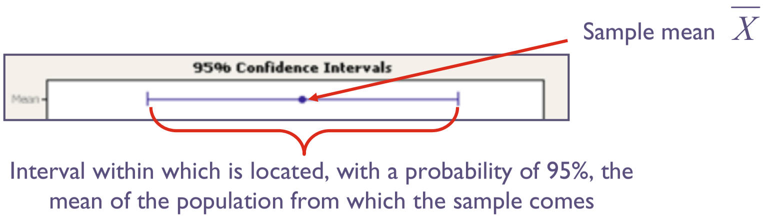
What is it?

- The Confidence Interval (CI)[G] is the interval that contains the mean (or proportion, median, standard deviation) of the population with a probability of 95%

When to use it:

- The Confidence Interval is used to identify whether the analyzed sample belongs to a certain population

Overview:



Confidence Interval

The formula for determining the width of the Confidence Interval for the mean of a sample is:

$$CI_{\mu} = \bar{X} \pm 2\frac{s}{\sqrt{n}}$$

where:

$\bar{X}$ = Sample mean

CI = 95% Confidence interval

n = Sample size

s = Sample standard deviation*

Example: Estimation of the mean width of a particular mechanical part

$\bar{X}$ = 21.0 mm
s = 0.25 mm
n = 25

CI = (21.0 ± 0.098)

*when the population standard deviation is known, use it instead of the sample standard deviation (s)

Confidence Interval

The following formula is used to determine the width of the Confidence Interval for the proportion of a sample:

$$CI_P = \bar{p} \pm 2\sqrt{\frac{\bar{p} \times (1-\bar{p})}{n}}$$

where:

$\bar{p}$ = Sample proportion estimate

CI = 95% Confidence Interval

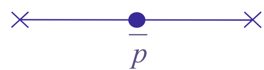
n = Sample size

Example: Estimate in order to assess the proportion of defects in a specific process

$\bar{p} = 0.15$

$n = 25$

$CI = (0.15 \pm 0.0714)$



Graphical Summary

Objective:

- The tool aims to give graphical and statistical representation of the parameters found in the collected data

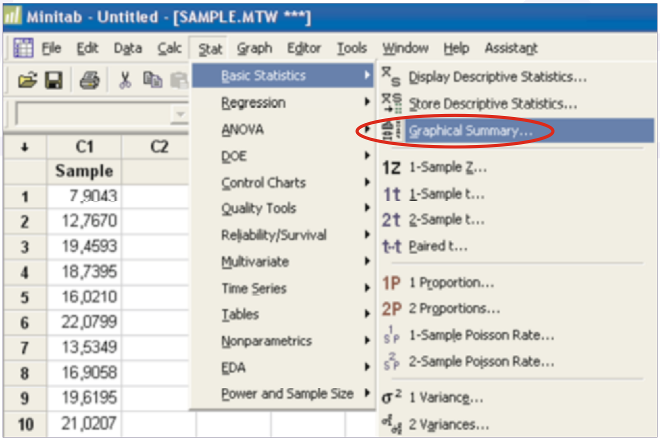
Characteristics (see page 72):

- Histogram with reference curve → A
- Normality Test → B
- *Basic Statistics* → C
- Verification of *Outliers* [(G)] presence → D
- Confidence Interval → E

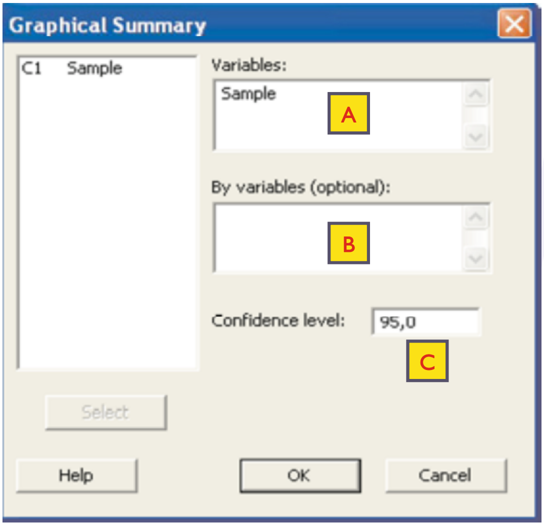
Graphical Summary

MINITAB:

Stat > Basic Statistics > Graphical Summary…



Graphical Summary



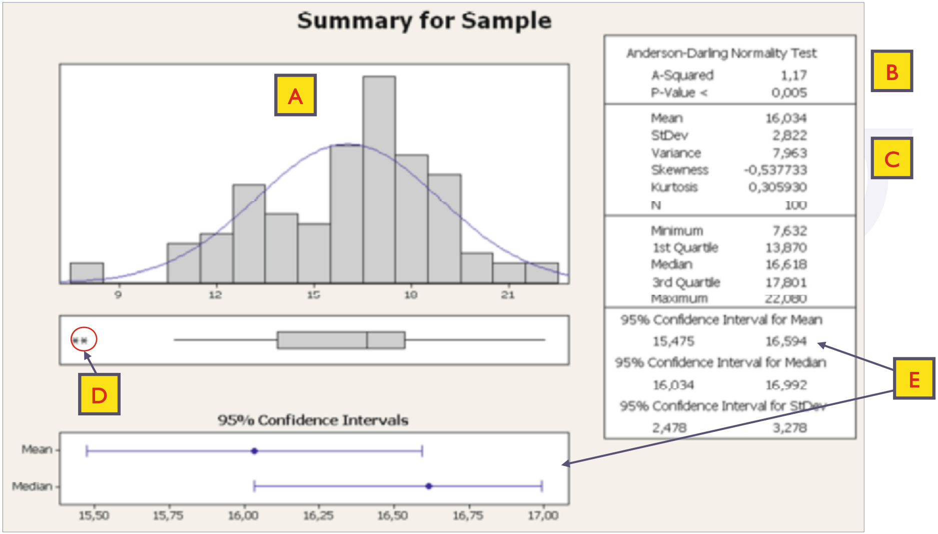
A Insert the column containing the sample to be analyzed

B Insert potential stratification factors

C Choose the level of confidence to determine the width of the Confidence Intervals

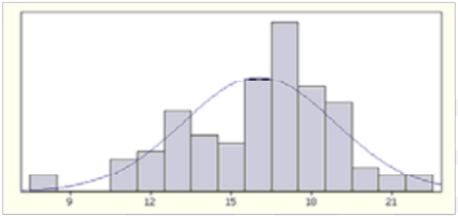
Graphical Summary

MINITAB: Output



Graphical Summary

A



- This is a schematic Bar Chart (Histogram)
- The chart is useful to check on a qualitative way the pattern of data collected in terms of mean, variability and presence of any abnormalities such as outliers, mixture of two distributions, etc.
- This chart shows the normal curve that best fits the data shown

B

Anderson-Darling Normality Test	
A-Squared	1,17
P-Value <	0,005

- It reports the results of the Anderson-Darling statistical test in order to verify the normality of the sample:
  - if the *P-Value* (G) is bigger than the threshold value chosen (generally 0.05, that is 5%), it is possible to say that the sample comes from a normal distribution
  - if the P-Value is less than the threshold value chosen, the sample data doesn't respect a normal distribution

Graphical Summary

C

Mean	16,034
StDev	2,822
Variance	7,963
Skewness	-0,537733
Kurtosis	0,305930
N	100
Minimum	7,632
1st Quartile	13,870
Median	16,618
3rd Quartile	17,801
Maximum	22,080

- This section has a summary of data through the usage of the parameters of location, dispersion, symmetry and sample size (see pages 60 and 61)
- **Location parameters**: Mean, Median, First Quartile, Third Quartile
- **Dispersion parameters**: Minimum, Maximum, Standard Deviation (StDev)
- **Shape parameters**: Skewness, Kurtosis

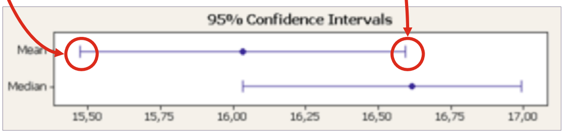
D

- D is a graph of the sample data through the use of the Boxplot
- The symbols * highlight points that may not belong to the same distribution of the remaining data
- These points are called Outliers and can often be associated with special events

Graphical Summary

E

95% Confidence Interval for Mean	
15,475	16,594
95% Confidence Interval for Median	
16,034	16,992
95% Confidence Interval for StDev	
2,478	3,278



- Seen in this chart are confidence intervals (with confidence level of 95%) for the estimation on population, which the sample of the analyzed data comes from:
  - Confidence Interval for mean
  - Confidence Interval for median
  - Confidence Interval for Standard Deviation

Boxplot

Objective:

- The Boxplot is a tool useful for studying the distribution of collected data and to obtain information on position, dispersion, and symmetry

When to use it:

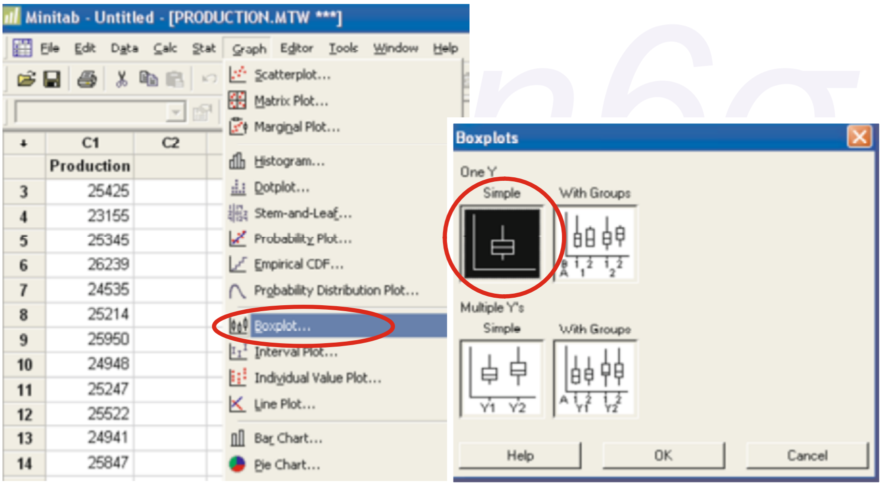
- With the Boxplot you can see if any Outliers exist (if yes, an investigation must be done to find out the reasons), or if there are any points not belonging to the same distribution of the remaining data, they must be probed, too

Lean6σ

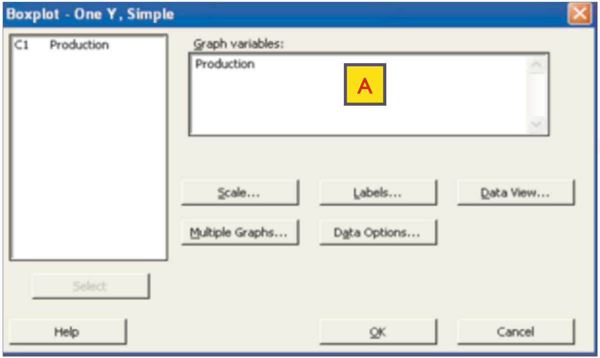
Boxplot

MINITAB:

Graph > Boxplot…



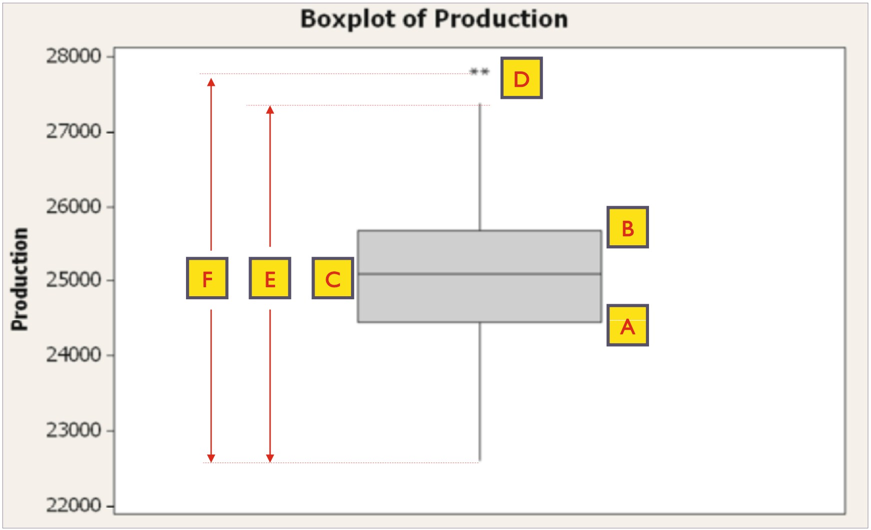
Boxplot



A

Select the variable stored in a single column to be plotted

Boxplot


Boxplot of Production
Production
28000
27000
26000
25000
24000
23000
22000
D
B
A
C
E
F

Boxplot

A **Lower Quartile or First Quartile (Q_1):** Cut-off point for lowest 25% of data

B **Upper or Third Quartile (Q_3):** Cut-off point for lowest 75% of data (or highest 25% of data)

C **Median (Q_2):** Cut-off point for 50% of data (50th percentile)

D **Outliers:** Observations that are numerically distant from the rest of data, i.e. unusually large or small data points (verify why they are present!). Minitab uses the quartile method

$$\begin{cases} LS = Q_3 + 1,5(Q_3 - Q_1) \\ LI = Q_1 - 1,5(Q_3 - Q_1) \end{cases}$$

QUARTILE METHOD

E **Upper whisker and Lower whisker:** These are estimates of the upper and lower limits of the data set (excluding outliers)

F **Range:** Maximum – Minimum

Gage R&R

Objective:

- Gage R&R is a measurement of the capability of a measurement system to obtain the same measurement reading consistently with repeated measurement takings. Gage R&R decomposes the total variation in measured data into part to part variation and measurement variation, and determines the capability of the measurement system by comparing measurement variation vs total variation

Components of Variation :

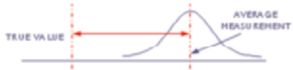
$$\sigma^2_{total} = \sigma^2_{part-to-part} + \sigma^2_{measurement}$$

$$\sigma^2_{measurement} = \sigma^2_{repeatability} + \sigma^2_{reproducibility}$$

The measurement system is valid if the greater part of variability is attributable to the process ($\sigma_{part\ to\ part}$)

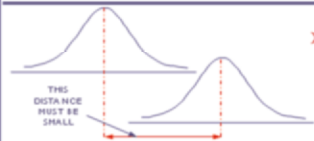
Gage R&R

R&R

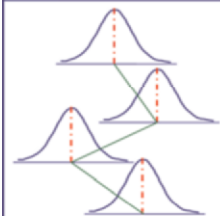


➤ **Accuracy:**
Is a measure of the distance between the average value of the measurement of a part and the true value of the part

➤ **Repeatability:**
Is the consistency of a single operator to measure the same part. Multiple times with the same measurement system; it is related to the standard Deviation of measured values



➤ **Reproducibility:**
Is the consistency of different operators in measuring the same part with the same measurement system; it is related to standard deviation of the Distribution of operator averages



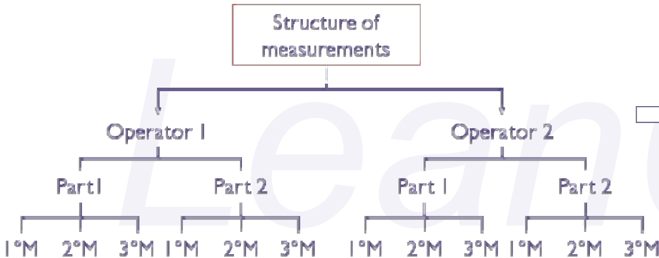
➤ **Stability:**
Is the ability of a measurement system to produce the same values over time when measuring the same sample

➤ **Resolution**
Is the capability to detect the smallest acceptable change. To achieve adequate resolution, it is required that increments in the measurement system should be one tenth of the product specification or process variation

(Source: AIAG, *Automotive Industry Action Group*)

Gage R&R (Continuous Data)

Gage R&R Test Plan (Manual):



Parts	Operators	Measurements
1	Operator 1	97,500
1	Operator 1	97,870
1	Operator 1	97,516
1	Operator 1	97,685
1	Operator 2	98,055
1	Operator 2	97,870
1	Operator 2	98,018
1	Operator 2	97,685
2	Operator 1	100,140
2	Operator 1	100,088
2	Operator 1	100,236
2	Operator 1	99,940

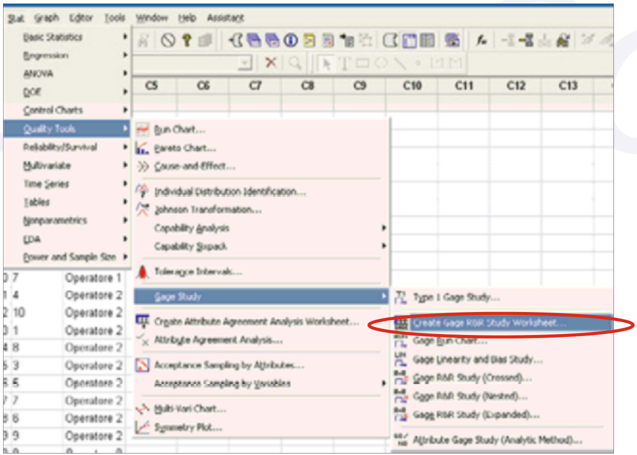
1. Each operator will measure each part multiple times (recommended 3 times)
2. The data must be balanced, i.e., each operator must measure the same part equal number of times
3. The selected parts must be representative of the range of variation of the process
4. Operators should carry out the tests “blindly”, i.e. without being influenced by other operators’ measurements, and sequence their measurement jobs randomly

Gage R&R (Continuous Data)

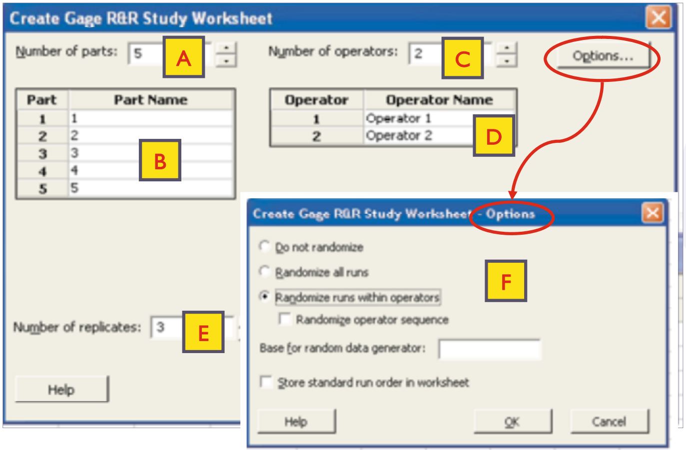
Gage R&R Test Plan (Automatically Created by Minitab):

MINITAB:

Quality Tools > Gage Study > Create Gage R&R Study Worksheet…



Gage R&R (Continuous Data)



A Select the number of parts to be measured

B Enter part number/name

C Select the number of operators

D Enter the name/label for operators

E Select the number of replicates

F Select this option if you want to randomize the test

Gage R&R (Continuous Data)

MINITAB: Output

StdOrder	RunOrder	Parts	Operators	Measurement
7	1	4	Operator 1	
3	2	2	Operator 1	
9	3	5	Operator 1	
5	4	3	Op	
1	5	1	Op	
2	6	1	Operator 2	
10	7	5	Operator 2	
8	8	4	Operator 2	
4	9	2	Operator 2	
6	10	3	Operator 2	
15	11	3	Operator 1	
13	12	2	Operator 1	
19	13	5	Operator 1	
11	14	1	Operator 1	
17	15	4	Operator 1	
20	16	5	Operator 2	
12	17	1	Operator 2	
18	18	4	Operator 2	
16	19	3	Operator 2	
14	20	2	Operator 2	
21	21	1	Operator 1	
25	22	3	Operator 1	
29	23	5	Operator 1	
23	24	2	Operator 1	
27	25	4	Operator 1	
26	26	3	Operator 2	

A B C D E

```
Gage R&R Study Worksheet

Parts:        5     Operators:     2
Replicates:   3     Total runs:   30
```

A
Standard order of test (without randomization)

B
Randomized test run order

C
Part number to be measured in each run

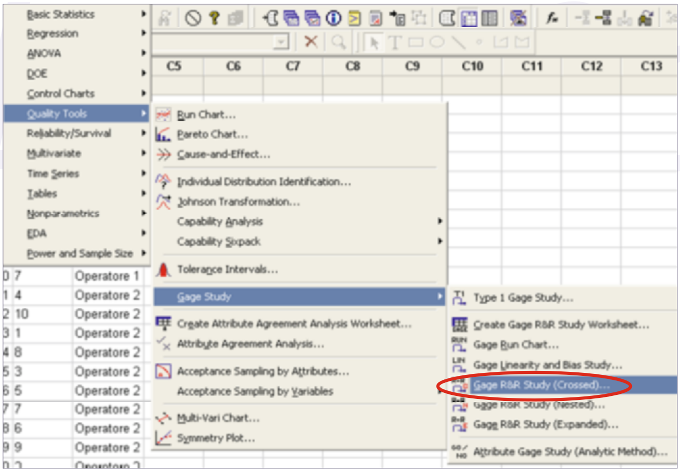
D
Operator number/name

E
Measurement data to be entered

Gage R&R (Continuous Data)

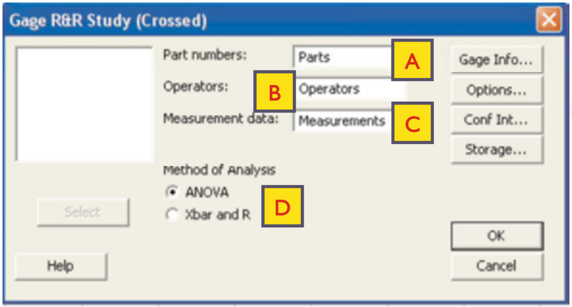
Analysis of Gage R&R with MINITAB:

Stat > Quality Tools > Gage Study > Gage R&R Study (Crossed)…



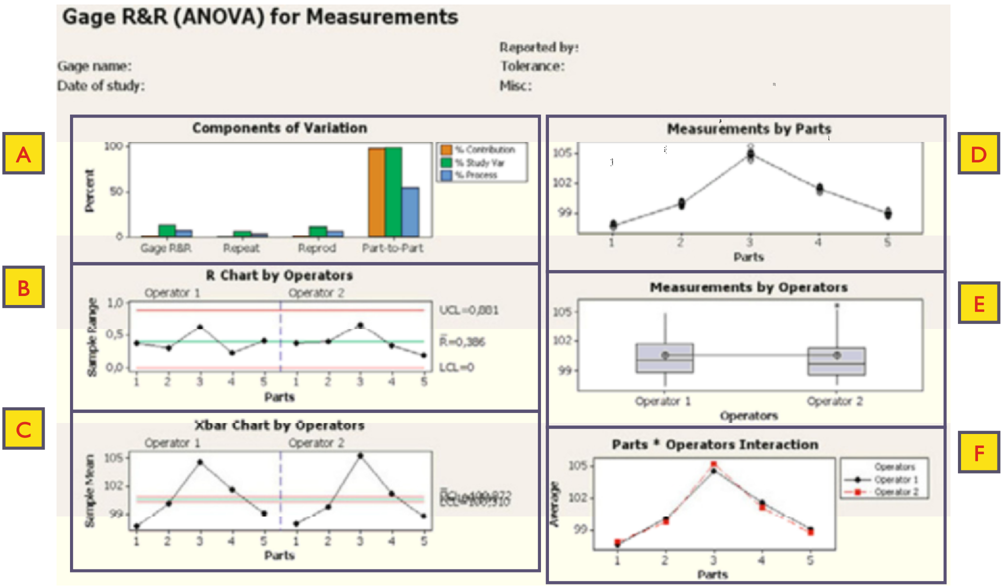
Gage R&R (Continuous Data)

Gage R&R Study (Crossed)…



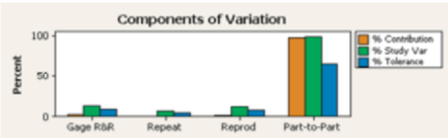
- **A** Enter the parts name/label column
- **B** Enter operators name/label column
- **C** Enter the measurements data column
- **D** Choose the most appropriate analysis method

Gage R&R (Continuous Data)



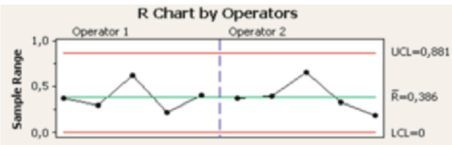
Gage R&R (Continuous Data)

A



- Each set of bars represents a source of variation. By default there are *% Contribution* and *% StudyVar,* but if you enter the option of *Tolerance* (or the *Historical Tolerance*) , it shows a third bar *% Tolerance*
- In a good measurement system the biggest contributor of variability should be the *Part-to-Part Variation*
- Note that, in case of *% StudyVar and % Tolerance,* the sum of the bar heights of repeatability and reproducibility will not be equal to the bar height of Gage R&R. This is because the standard deviations will not add up (unlike σ^2)

B



- The *R-chart* shows the variability in the measurements for each operator
- Specifically, it shows:

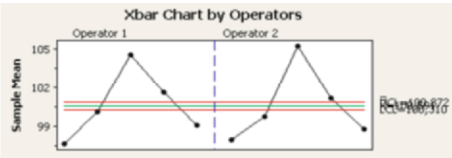
  - each dot in the R-chart for a particular operator shows the range (maximum-minimum) of repeated measurements; if they are same, the range will be zero

  - the *Center line* is calculated by averaging all the ranges for each subgroup of repeated measurements for each part

  - *Control Limits* (UCL and LCL) are computed by using the variance within the subgroups

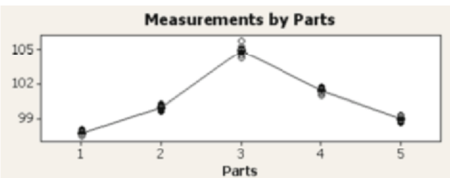
Gage R&R (Continuous Data)

C



- The X-bar chart shows *Part-to-Part* variation by displaying the mean of repeated measurements of each part
- Specifically, it shows:
  - the dots in the chart represent, for each operator, the mean of repeated measurements of each part
  - the *Center Line* represents the mean of all measurements from all operators and all parts
  - *Control Limits* (UCL and LCL) are calculated from measurement data
- The measurement system is acceptable when plotted dots are out of control limits
- The variation caused by Repeatability should be much smaller than *Part-to-Part* variation

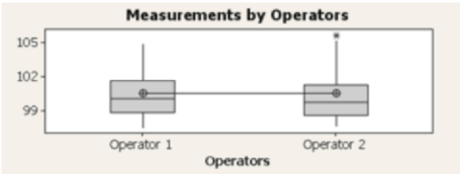
D



- This chart shows the dotted plots for the measured values of each part aggregating all operators
- In the chart, circles are individual measurements, solid dots represent mean value of measurements for each part
- Ideally:
  - measurements for each part should closely cluster together, with little variation
  - part-to-part measurement variation should be much larger than the variation of measurements on the same part

Gage R&R (Continuous Data)

E



- *Measurement by operator* graph may help to determine if reproducibility will affect the measurements
- It shows all the measurements taken by different operators: the circles show averages. The line connects the mean measurements for each operator
- With this graph, we can also determine whether the total variability in the parts is the same for each operator (variability should have similar mean and variation)

- Guidelines AIAG

Line condition…	Indication…
Parallel to X-axis	Operators yield similar measurement means
Not parallel to X-axis	Operators yield different measurement means. This indicates operators measure in different ways

Gage R&R (Continuous Data)

F

- This *Operator*Part Interaction* chart shows lines that connect the mean measurements for each operator measuring each part; each line indicates an operator
- In an ideal situation, all lines should be coincidental with each other, indicating no operator induced measurement variation among all parts

- Guidelines AIAG

Line condition	Indication
Virtually parallel	The operators measure parts in a similar way
A line is substantially higher or lower than others	An operator consistently yields measurements higher or lower than others
Non parallel or crossed lines	The results of the operators' measurements are affected by different parts

Gage R&R (Continuous Data)

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Parts	4	244,805	61,2012	129,630	0,000
Operators	1	0,022	0,0221	0,047	0,839
Parts * Operators	4	1,888	0,4721	13,973	0,000
Repeatability	30	1,014	0,0338		
Total	39	247,728			

A

Alpha to remove interaction term = 0,25

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0,14337	1,85
Repeatability	0,03379	0,44
Reproducibility	0,10958	1,42
Operators	0,00000	0,00
Operators*Parts	0,10958	1,42
Part-To-Part	7,59113	98,15
Total Variation	7,73451	100,00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	0,37865	2,2719	13,61
Repeatability	0,18382	1,1029	6,61
Reproducibility	0,33103	1,9862	11,90
Operators	0,00000	0,0000	0,00
Operators*Parts	0,33103	1,9862	11,90
Part-To-Part	2,75520	16,5312	99,07
Total Variation	2,78110	16,6866	100,00

B

Number of Distinct Categories = 10

C

A

Identifying significance of source of variability by p value:

For a main effect, a p value less than 5% indicates its significance and for an interaction less than 25% may indicate its significance.

B

Rule of thumb: Performance level of a gage (threshold values of acceptability)

% R&R (% Study Var)	Performance Level
0 - 10 %	Good
10 - 30 %	Marginal
> 30 %	Unacceptable

C

NDC (*Number of Distinct Categories*) ≥ 5

Gage R&R (Attribute Discrete Data)

Gage R&R Test Plan:

Example of Gage R&R Test for Good/Not Good Judgments

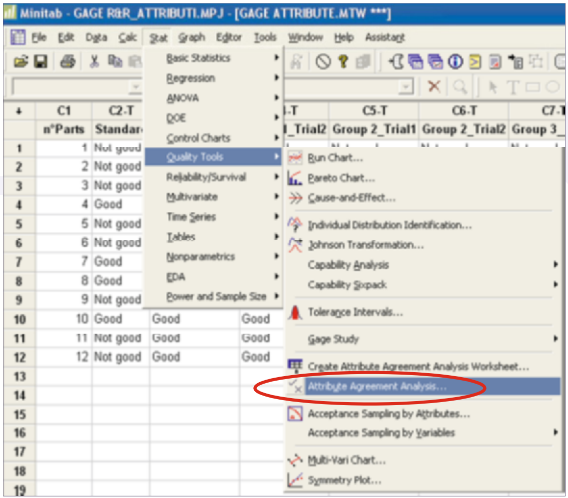
n°Parts	Standard	Group 1_Trial1	Group 1_Trial2	Group 2_Trial1	Group 2_Trial2	Group 3_Trial1	Group 3_Trial2
1	Not good	Not good	Not good	Not good	Not good	Not good	Not good
2	Not good	Not good	Not good	Not good	Not good	Not good	Not good
3	Not good	Not good	Not good	Not good	Not good	Not good	Not good
4	Good	Good	Good	Good	Good	Not good	Good
5	Not good	Good	Good	Good	Good	Not good	Not good
6	Not good	Good	Good	Good	Not good	Not good	Not good
7	Good	Good	Good	Not good	Good	Not good	Good
8	Good	Good	Good	Good	Good	Not good	Good
9	Not good	Not good	Not good	Not good	Not good	Not good	Not good
10	Good	Good	Good	Good	Good	Not good	Good
11	Not good	Good	Good	Good	Good	Not good	Good
12	Not good	Good	Good	Good	Not good	Not good	Not good

- Select 20-30 parts that can show the variability of the process
- Use an expert to evaluate all selected parts in order to create a standard reference value
- Use 2 or 3 operators to evaluate all parts and give good/not good ratings
- Apply randomization and blinding in the test

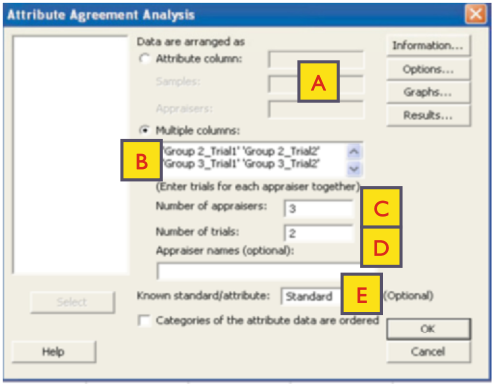
Gage R&R (Attribute Discrete Data)

MINITAB:

Stat > Quality Tools > Attribute Agreement Analysis…

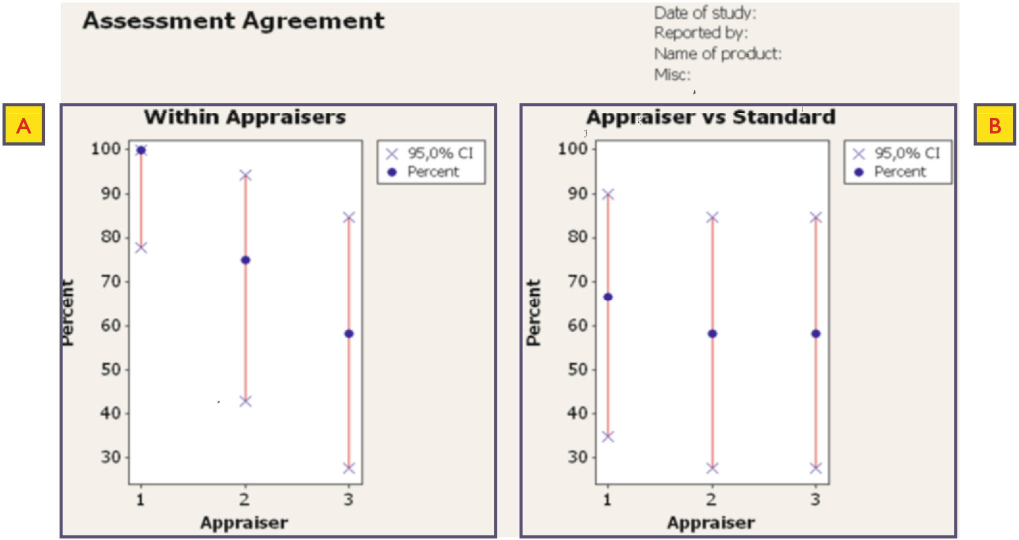


Gage R&R (Attribute Discrete Data)

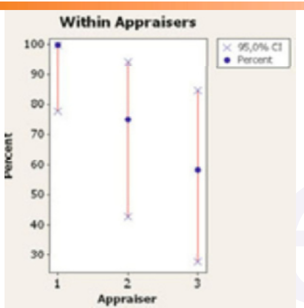


A Use this option when data are grouped in columns
B Use this option when different evaluation trials are stored in different columns
C Enter the number of operators
D Enter the number of trials
E Enter the standard reference value (if available)

Gage R&R (Attribute Discrete Data)

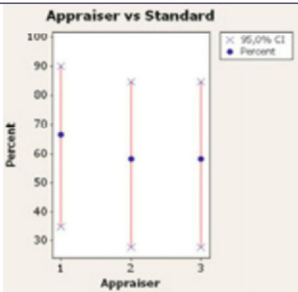


Gage R&R (Attribute Discrete Data)



A

- This chart shows the consistency in responses for each operator
- For each operator
  - the blue dot shows the percentage of consistency in his/her answers
  - the red line gives the 95% confidence interval for the percentage of consistency in his/her answers
  - the blue X provides the upper and lower confidence limits



B

- This chart is generated when there is a standard as reference
- This chart shows the correctness of responses for each operator (accuracy in the answer)
- For each operator, the chart provides the following information:
  - the blue dot shows the percentage of consistency with the standard of reference
  - The red line represents 95% confidence interval of the percentage of consistency with the standard of reference
  - The blue X represents the upper and lower limit points of the confidence interval

Gage R&R (Attribute Discrete Data)

Attribute Agreement Analysis for Group 1_Tria; Group 1_Tria; Group 2_Tria; ...

Within Appraisers A

Assessment Agreement

B C

Appraiser	# Inspected	# Matched	Percent	95 % CI
1	12	12	100,00	(77,91; 100,00)
2	12	9	75,00	(42,81; 94,51)
3	12	7	58,33	(27,67; 84,83)

Matched: Appraiser agrees with him/herself across trials.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
1	Good	1,00000	0,288675	3,46410	0,0003
	Not good	1,00000	0,288675	3,46410	0,0003
2	Good	0,49650	0,288675	1,71994	0,0427
	Not good	0,49650	0,288675	1,71994	0,0427
3	Good	-0,26316	0,288675	-0,91161	0,8190
	Not good	-0,26316	0,288675	-0,91161	0,8190

Each Appraiser vs Standard D

Assessment Agreement

E F

Appraiser	# Inspected	# Matched	Percent	95 % CI
1	12	8	66,67	(34,89; 90,08)
2	12	7	58,33	(27,67; 84,83)
3	12	7	58,33	(27,67; 84,83)

Matched: Appraiser's assessment across trials agrees with the known standard.

- **A** Comparing operators
- **B** Percentage consistency for each operator (without comparing with standard)
- **C** Confidence Intervals on percentage consistency
- **D** Comparing operators with standard
- **E** Percentage correctness of each operator
- **F** Confidence Intervals on correctness

Rule of Thumb: Performance evaluation standard for attribute Gage R&R

B E

Percent	Performance Level
90 - 100 %	Good
80 - 90 %	Marginal
< 80 %	Unacceptable

Gage R&R (Attribute Discrete Data)

Between Appraisers A

Assessment Agreement

# Inspected	# Matched	Percent B	95 % CI C
12	4	33,33	(9,92; 65,11)

Matched: All appraisers' assessments agree with each other.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
Good	0,398142	0,0745356	5,34164	0,0000
Not good	0,398142	0,0745356	5,34164	0,0000

All Appraisers vs Standard D

Assessment Agreement

# Inspected	# Matched	Percent E	95 % CI F
12	4	33,33	(9,92; 65,11)

Matched: All appraisers' assessments agree with the known standard.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
Good	0,351145	0,117851	2,97957	0,0014
Not good	0,351145	0,117851	2,97957	0,0014

- **A** Comparison between operators
- **B** Percentage of consistency between different operators (similar to the concept of reproducibility)
- **C** Confidence Interval for percentage consistency
- **D** Comparison of all operators with standard
- **E** Percentage of correctness among all operators vs standard
- **F** Confidence Interval

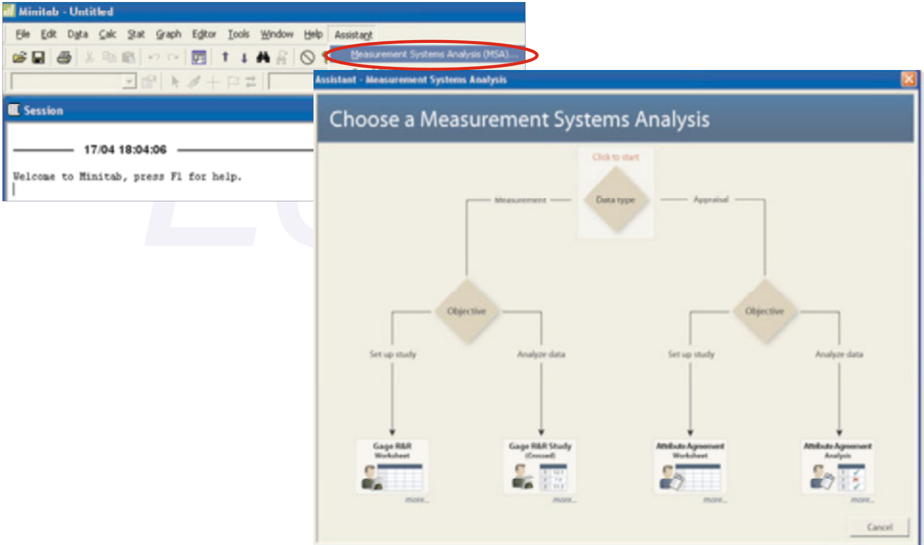
Rule of Thumb: Performance evaluation standard for Gage R&R with discrete attributes

B, E

Percent	Performance Level
90 - 100 %	Good
80 - 90 %	Marginal
< 80 %	Unacceptable

Gage R&R & Minitab

Minitab Assistant helps you to choose the right Gage R&R methodology



Pareto Diagram

Objective:

- Pareto diagram can help to identify high priority actions or areas, by graphically displaying them in terms of frequencies or scores in decreasing order, which allows us to focus our intervention and resources in key areas

Features:

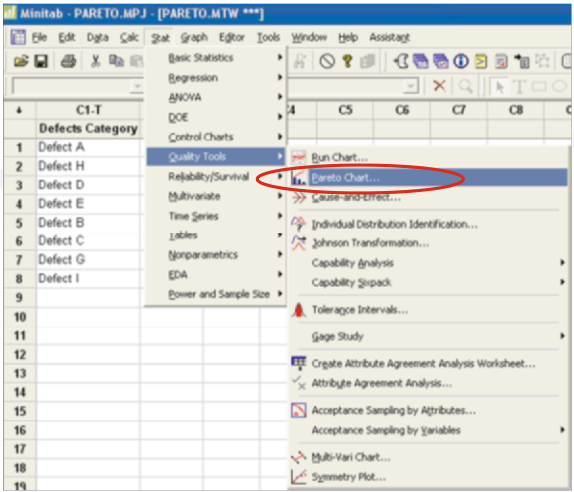
- This tool will allow management to focus on high impact area
- This is also a supporting tool for diagnosis of current situation and determination of priorities

Lean6σ

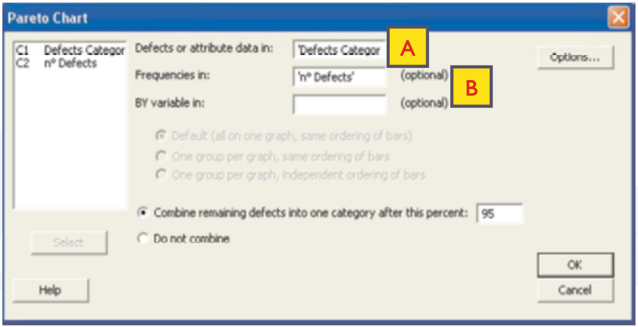
Pareto Diagram

MINITAB:

Stat > Quality Tools > Pareto Chart…



Pareto Diagram



Defects Category	n° Defects
Defect A	56
Defect H	76
Defect D	38
Defect E	154
Defect B	75
Defect C	24
Defect G	14
Defect I	5
Defect A	345
Defect H	83
Defect D	75

Raw data

Defects Category	n° Defects
Defect A	1342
Defect H	765
Defect D	374
Defect E	154
Defect B	75
Defect C	24
Defect G	14
Defect I	5

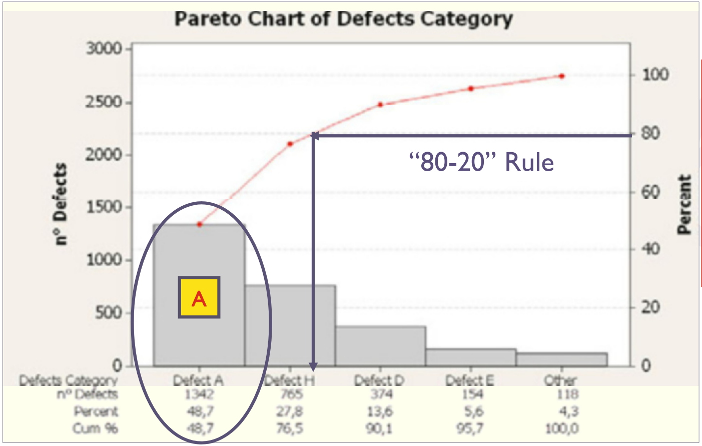
Grouped data

A Insert the column that contains defect labels (names)

B Insert the column that contains frequency of occurrences for defects

Pareto Diagram

MINITAB: Output



A

A is the item that is most critical to business:

Completely removing defect type A would reduce total defects by 48.7%

Normality Test

Objective:

- The normality test is a statistical test that checks the validity of the assumption on data to be normally distributed. This normality assumption is critical for many statistical analyses

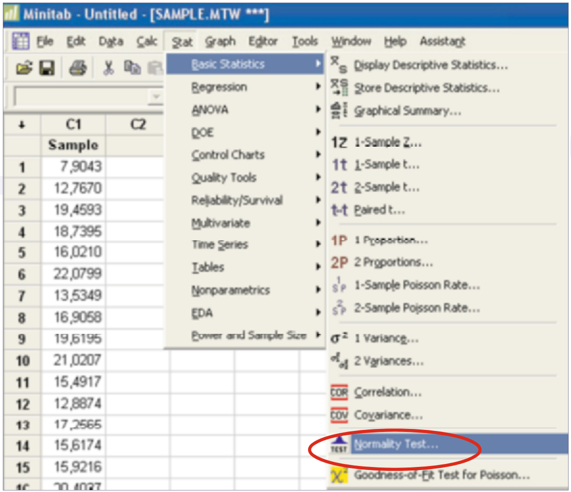
Statistical tools that need normality assumption:

- *1-Sample t*
- *2-Sample t*
- *Paired t-Test*
- ANOVA
- *Control Chart* for continuous data
- *Capability Analysis*

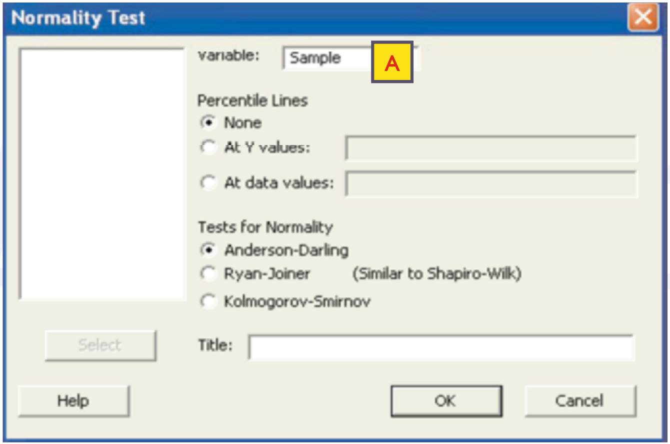
Normality Test

MINITAB:

Stat > Basic Statistics > Normality Test…



Normality Test

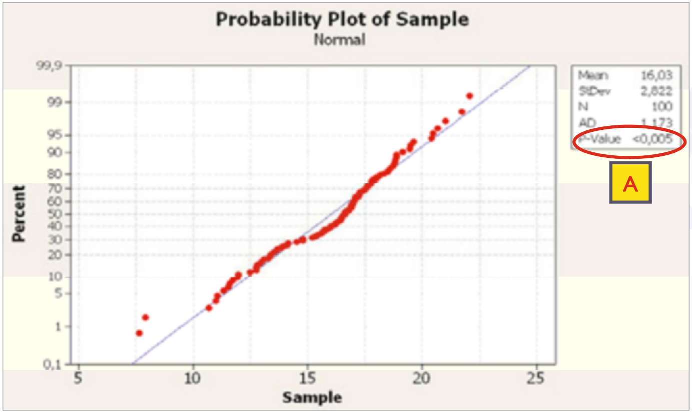


A

Insert the column that contains data to be tested for normality

Normality Test

MINITAB: Output



A

Data are **not normal** because the P-Value is less than **0.05**

P-Value > 0.05 ⟶ Data are normal

P-Value < 0.05 ⟶ Data are not normal

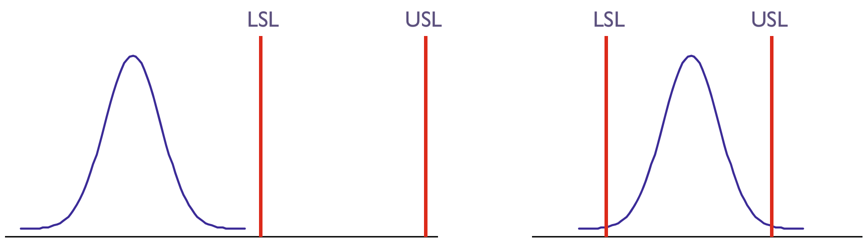
Capability Analysis

Objective:

- Capability Analysis or *Process Capability Analysis* (G) is a study to determine the ability of current process to satisfy customer required specifications

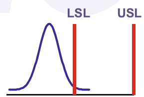
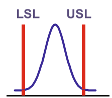
Basic Assumptions:

- Normal data
- Stable process



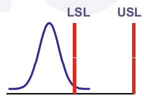
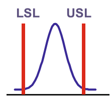
Capability Analysis

Short Term (ST)	
Potential capability index	Actual capability index
A $C_p = \frac{USL - LSL}{6\sigma_{ST}}$	B $C_{pk} = \min\left\{\frac{USL - \mu}{3\sigma_{ST}}; \frac{\mu - LSL}{3\sigma_{ST}}\right\}$

A		Cp does not take into account the process centering
B		Cpk takes into account the process centering

Capability Analysis

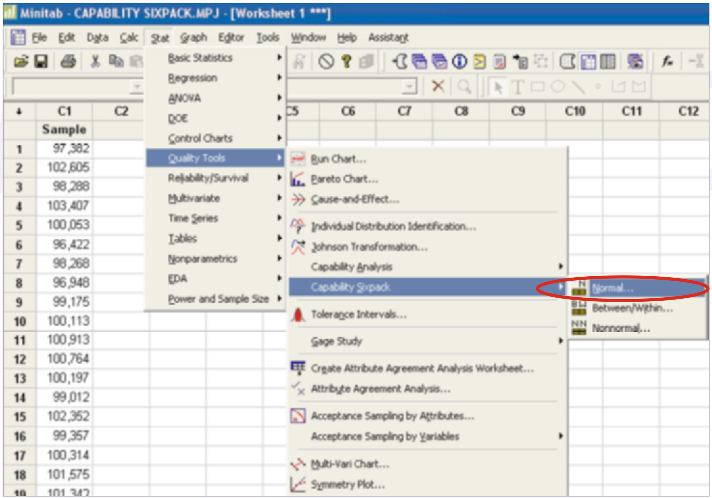
Long Term (LT)	
Potential performance capability index	Actual performance capability index
A $P_p = \frac{USL - LSL}{6\sigma_{LT}}$	B $P_{pk} = \min\left\{\frac{USL-\mu}{3\sigma_{LT}};\frac{\mu-LSL}{3\sigma_{LT}}\right\}$

A		Pp does not take into account the process centering
B		Ppk takes into account the process centering

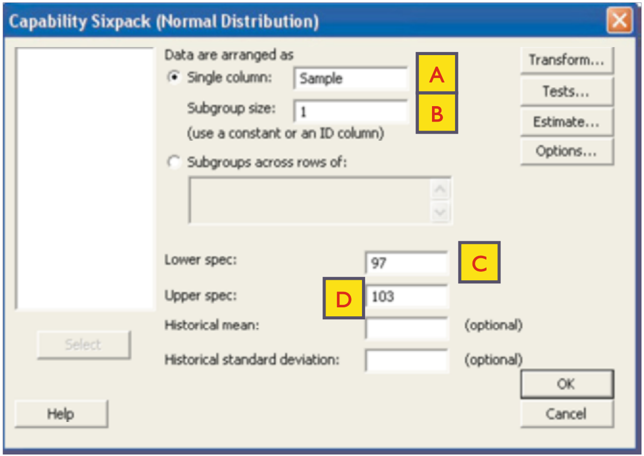
Capability Analysis

MINITAB:

Stat > Quality Tools > Capability Sixpack > Normal…



Capability Analysis



A

Insert the column that contains process data to be assessed for capability

B

Insert subgroup size by either in-puting a number or a subgroup index column

C

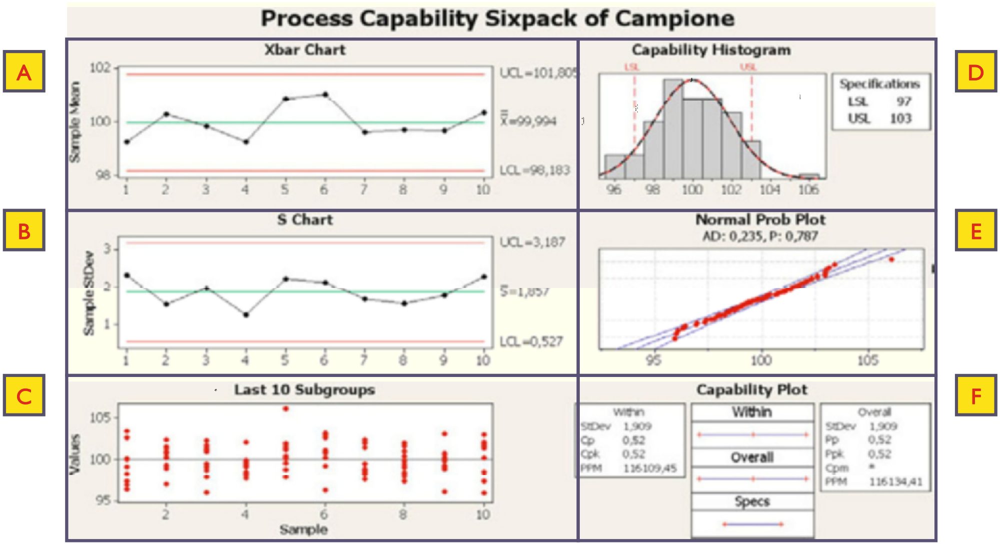
Insert lower specification limit

D

Insert upper specification limit

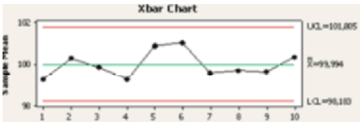
Capability Analysis

MINITAB: Output



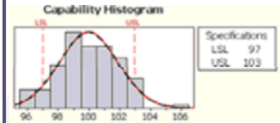
Capability Analysis

MINITAB: Output



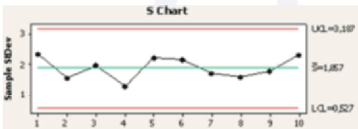
A

Xbar chart assesses the stability of sub-groups means



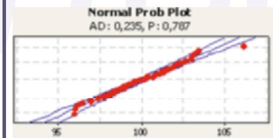
D

This chart shows the histogram for the data set and fitted normal distribution curves for both long term and short term variation



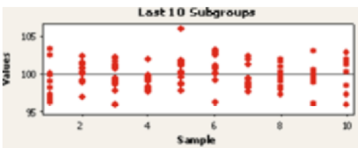
B

S chart assesses the stability of sub-groups variances



E

This graph checks normality of the data



C

This chart shows the trend of subgroups variations

F

This graph displays the values of Cp, Cpk, Pp, Ppk, StDev PPM based on *short term* and *long term*, and displays the natural variation of the process vs specifications

Calculation of DPMO

Objective:

- DPMO[G], *i.e. Defects Per Million of Opportunity* is a performance indicator calculated as a ratio of number of defects divided by the maximum number of potential defects in a batch of units inspected

Definitions:

- U = number of units inspected
- D = number of total defects
- O = number of opportunities for defect per unit inspected. It is the maximum number of potential defects of all failure modes for a unit

$$DPO = \frac{D}{U \times O} \Rightarrow DPMO = \frac{D}{U \times O} \times 1000000$$

Calculation of Process Sigma

Objective:

- *Process Sigma* (G) calculates Sigma level of a process based on defects detected in a batch of units

Calculation procedure:

Step 1	Number of opportunity per unit (O)	2
Step 2	Number of units inspected (U)	1000
Step 3	Number of defects found (D)	51
Step 4	Number of defects divided by total number of opportunities	0,0255
Step 5	Calculate performance level (process yield)	0,9745
Step 6	Determine Process Sigma value	3,45

$$DPO = \frac{51}{1000 \times 2}$$

$$\eta = 1 - \frac{51}{1000 \times 2} = 0.9745$$

Yield	DPMO	Sigma
95,05285%	49471	3,15
95,54345%	44565	3,20
95,99408%	40059	3,25
96,40697%	35930	3,30
96,78432%	32157	3,35
97,12834%	28717	3,40
97,44119%	25588	3,45
97,72499%	22750	3,50
97,98178%	20182	3,55

Takt Time

Objective:

- The *Takt Time* (G) represents the rhythm of production/delivery that a process (workstation, Cell, etc.) must respect to satisfy customer demand. Each step of the process must produce to Takt Time to ensure a stable flow of outputs to meet customer requirements

Calculation method:

$$\text{TAKT TIME} = \frac{\text{Available Time (Time)}}{\text{Customer Demand (pcs/Time)}}$$

$$\text{N° Operators necessary} = \frac{\text{Cycle Time}}{\text{Takt Time}}$$

Available Time: Total available time minus planned downtime (example: Breaks)

Customer Demand: Total expected demand from Customer (pieces per unit of time)

Cycle Time: Total manual working time for one cycle (Touch Time) plus automatic run time. In case of production mix, the weighted mean (weighted on quantity) can be useful

Takt Time

Step n° 1: Determine how fast the process (Takt Time) must be

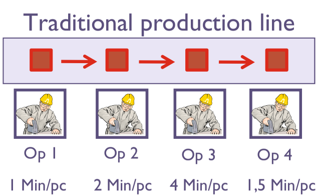
- Customer Demand: 35000 units/year
- Time per shift: 8 hours (1 shift per day)
- Breaks (2 x 15 minutes): 30 minutes

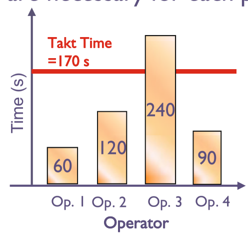
Time per shift (8 hours x 3600 seconds) = 28800 s
Breaks(30 minutes x 60 seconds) = 1800 s
Available time= 27000 s
Customer Demand / day = 35000 / 220 = 159 pieces

$$\text{TAKT TIME} = \frac{27000}{159} = 170 \text{ s}$$

The customer buys goods at the rate of one every 170 seconds. This is the "Target" frequency which all processes must reach to produce each part or component to meet customer demand

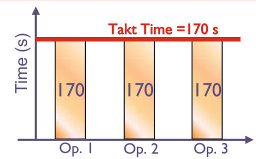
Step n° 2: Identify how many people are necessary for each process to satisfy Customer demand





- **Cycle time** = 60 + 120 + 240 + 90 = 510 s
(total time necessary for the production of one piece)

$$\textbf{No. Operators necessary} = \frac{510}{170} = 3 \text{ Ops.}$$



New asset: the contribution of the three operators in the production of each piece is the same and equal to Takt Time

Overall Equipment Effectiveness (OEE)

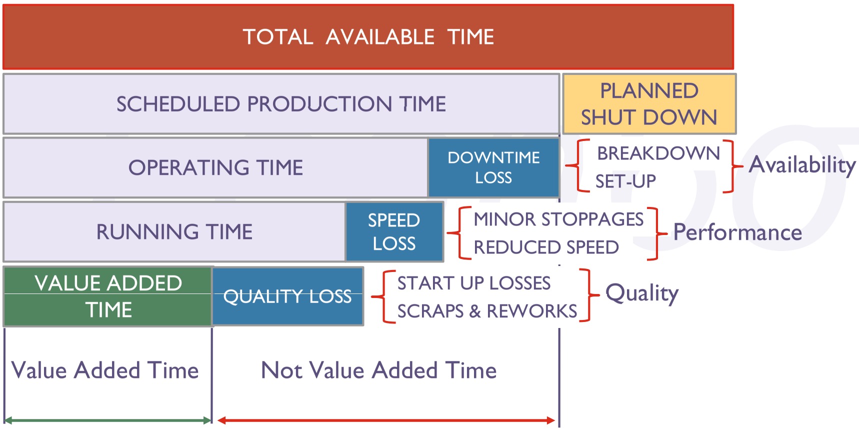
Objective:

- The OEE[(G)] (Overall Equipment Effectiveness) is a powerful method to monitor and improve the efficiency of manufacturing and transactional processes. OEE is frequently used as a key metric in TPM (Total Productive Maintenance) and Lean programs. One of the main goals is to reduce what are called the ***Six Big Losses*** clustered in three categories: **Downtime, Speed** and **Quality losses**

SIX BIG LOSSES	CATEGORY	EXAMPLE	NOTES
Breakdowns	Downtime Loss	Equipment failure Unplanned maintenance	The threshold value between a breakdown and a minor stoppage can change from company to company (in most common situations 5 minutes)
Setup	Downtime Loss	Setup/Changeover Material/Operator shortages Warm up Time	A good way to reduce this kind of loss is SMED (set-up reduction methodology)
Minor Stoppages	Speed Loss	Parts jam Checking Framed pieces	The general definition of minor stoppages is a stop less than 5 minutes that does not require Maintenance operator intervention
Reduced Speed	Speed Loss	Equipment wear Lack of equipment knowledge Operator inefficiency	These kinds of causes prevent the process from operating at maximun speed (theoretical speed)
Start Up Losses	Quality Loss	Scraps Reworks	Scraps produced during start up phase
Scraps and reworks	Quality Loss	Scraps Reworks	Scraps or reworks produced during production phase

Overall Equipment Effectiveness (OEE)

Overview:



$$OEE = \frac{\text{Value Added Time}}{\text{Scheduled production Time}} = \%$$

OEE represents the percentage of production time spent making good pieces (no quality loss), as fast as possible (no speed loss), without interruption (no downtime)

Overall Equipment Effectiveness (OEE)

How to calculate OEE index:

$$OEE = \frac{\text{Number of acceptable units produced}}{\text{Theoretical number of units that could have been produced in the scheduled time running at standard speed}} \times 100\%$$

Formula based on units

- Standard speed = 110 pieces/minutes
- Number of good units produced = 11253 pieces

$$OEE = \frac{11253}{110 \times 280} \times 100\% = \frac{11253}{30800} \times 100\% = 36\%$$

Average OEE = 60%
World Class OEE = 85%

Overall Equipment Effectiveness (OEE)

How to calculate OEE index considering the three OEE factors:

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \times 100\%$$

$$\text{Availability} = \frac{\text{Operating Time}}{\text{Scheduled Production Time}} \times 100\ \%$$

World Class = 90%

$$\text{Performance} = \frac{\text{Total pieces} \times \text{Theoretical time to produce 1 unit}}{\text{Operating time}} \times 100\ \%$$

World Class = 95%

$$\text{Quality} = \frac{\text{Good pieces}}{\text{Total pieces}} \times 100\ \%$$

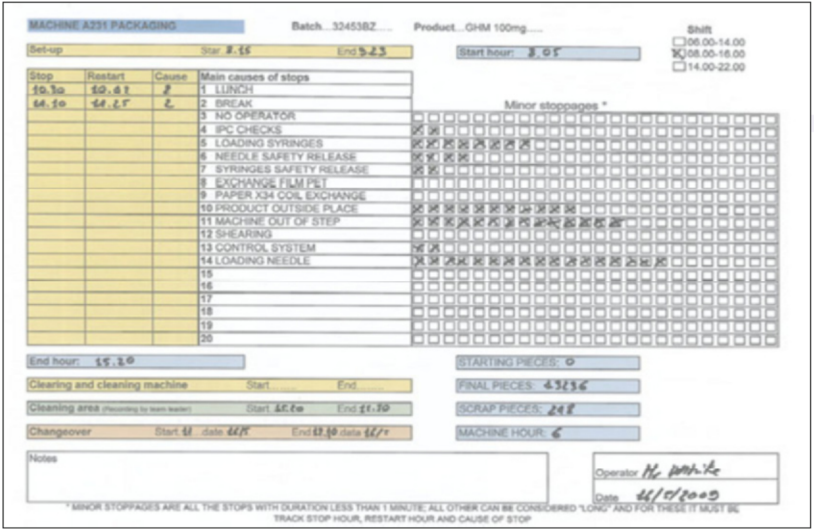
World Class = 99,9%

$$\text{OEE} = \frac{\text{Number of good pieces produced} \times \text{Theoretical time to produce 1 unit}}{\text{Scheduled production time}} \times 100\%$$

Formula based on time

Overall Equipment Effectiveness (OEE)

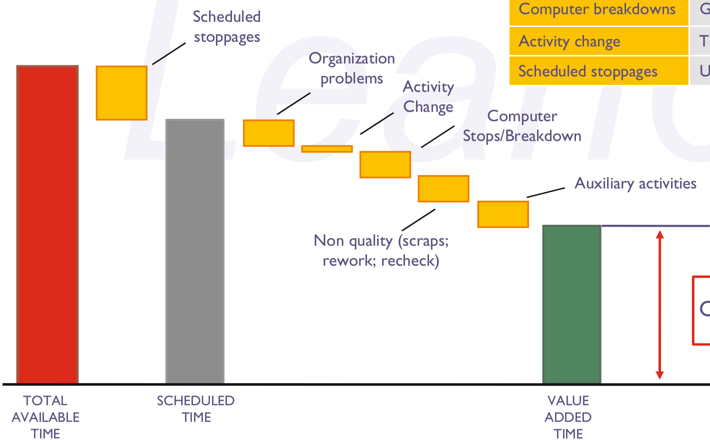
Example of the OEE data collection:



Overall Equipment Effectiveness (OEE)

How to apply OEE on a transactional process:

Organization Problem	Lack of operator. Lack of information. Role & Responsibility. Lack of flexibility
Computer breakdowns	Generally stoppages > 5 minutes
Activity change	Time to start a new application
Scheduled stoppages	Underload. IT Test



$$OEE = \frac{\text{Value Added Time}}{\text{Scheduled Time}} = \%$$

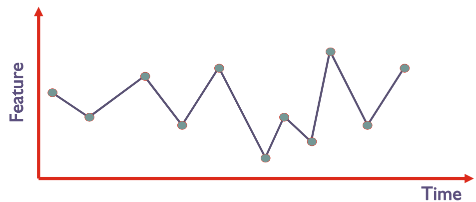
Time Series Plot

Objective:

- Time Series Plot is a tool to analyze a potential time trend in a sequence of data

Features:

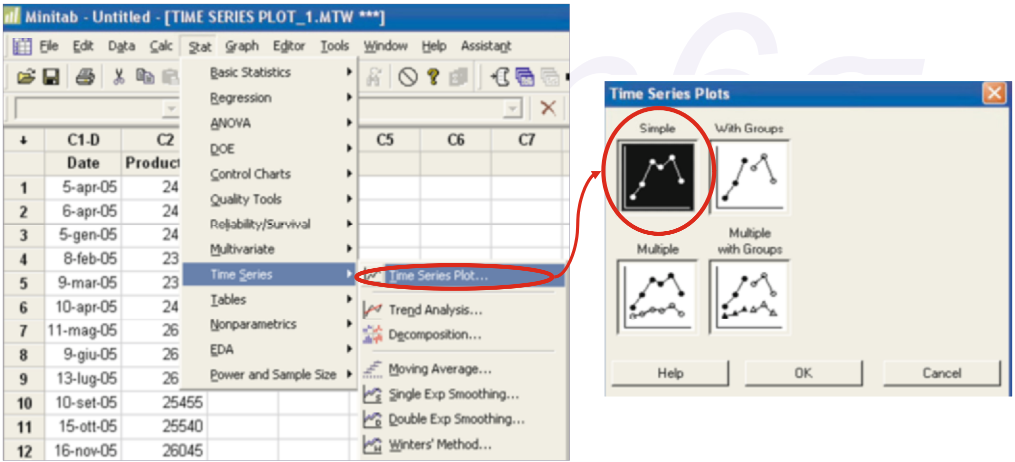
- It is a tool to analyze any trends over time, to assess the need to stratify the data (eg. cyclic patterns), to explore and validate the data before applying other tools (eg. Regression modeling)



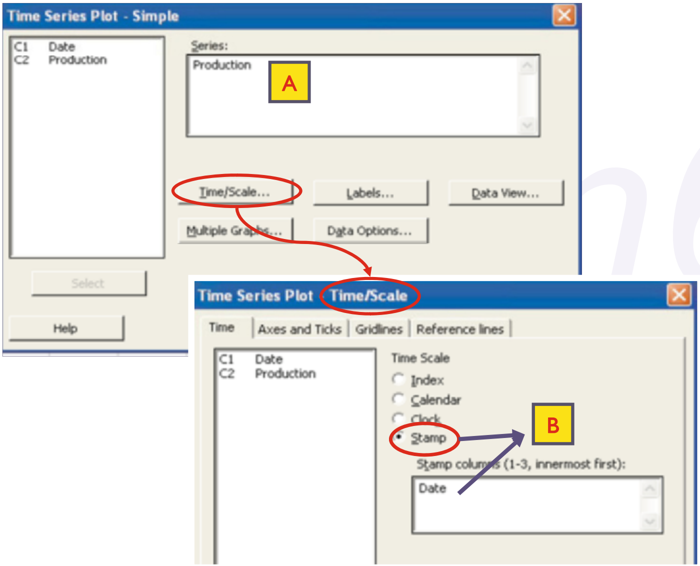
Time Series Plot

MINITAB:

Stat > Time Series > Time Series Plot…



Time Series Plot



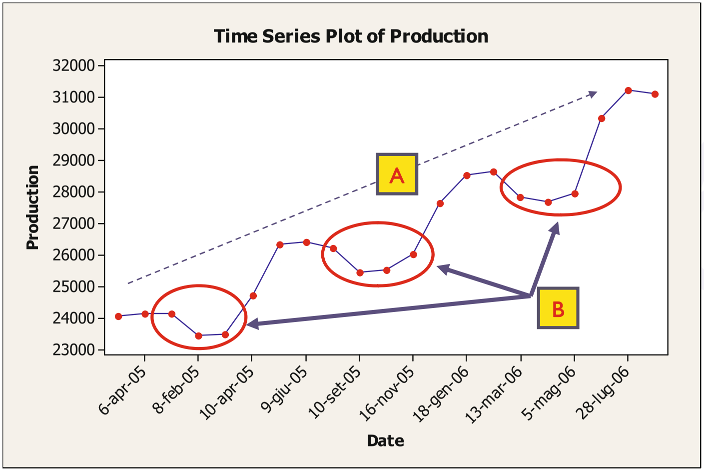
A

Select the column that contains the data to study time trends

B

Select "Stamp" and insert the columns containing appropriate time index labels for the data

Time Series Plot



A

It is possible to observe an increasing trend for production over time

B

Possible cyclic pattern: stratification might be needed (eg. day of the week)

Run Chart

Objective:

- Run Chart is a tool that identifies possible special causes for the process performance variation

Features:

- **Common Causes**[(G)]: Random causes are not attributable to special events, but to natural variability inherent in all processes
- **Special Causes**[(G)]: Special causes may be associated with special events, or else the result of temporal trends (*Clustering*, *Mixture*, *Trend*, *Oscillation*). If they are present the process will be "out of control"

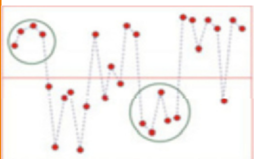
CAUTION:

The use of a Run Chart doesn't require normality assumption in process data

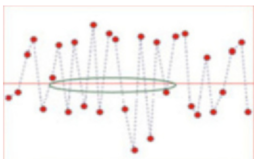
Run Chart

Patterns that indicate special causes:

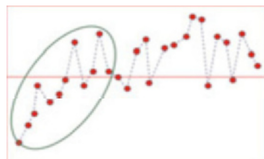
- *Clustering* is a pattern characterized by grouped data in a certain area of the graph (Clustering could be caused by variation in measurement systems, batch-batch variation, sampling issues)
- *Mixture* is a pattern in which a few points are near the median (Mixture is usually caused by a combination of two populations or processes operating at different levels)
- *Trend* is a pattern in a sequence of points increasing or decreasing (Trend could be caused by such things as worn out tools and fatigue of workers)
- *Oscillation* indicates fluctuating data that moves up and down rapidly and could mean that the process is unstable



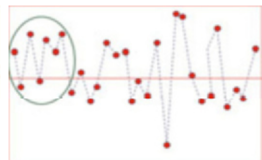
Clustering



Mixture



Trend



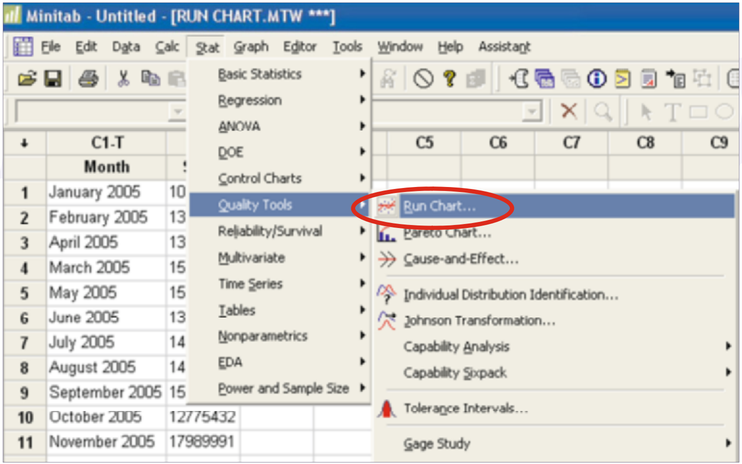
Oscillation

Run is defined as the number of consecutive points that are on the same side than the median

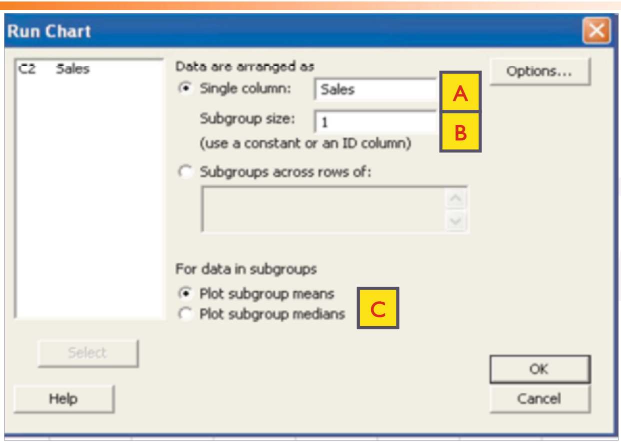
Run Chart

MINITAB:

Stat > Quality Tools > Run Chart…



Run Chart

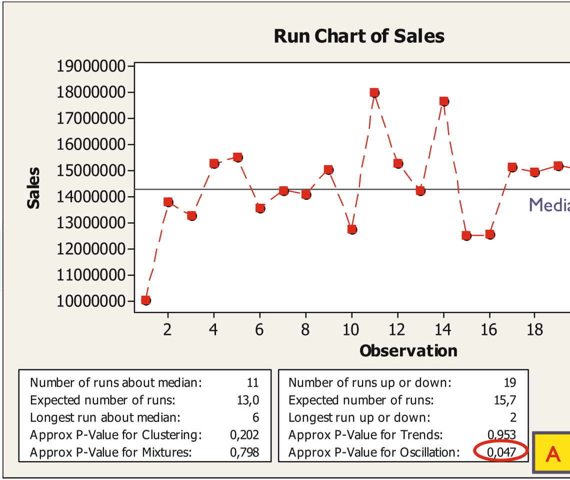


A Input column that contains the data to be plotted in run chart

B Input subgroup size

C For subgroup data, select either subgroup mean or median to be plotted in order to track the change in central tendency

Run Chart



A

The P-Value is less than 0.05 and indicates that there is significant oscillation

ANALYZE

Arcidiacono G., Calabrese C., Yang K.: Leading processes to lead companies: Lean Six Sigma.
DOI 10-1007/978-88-470-2492-2, © Springer-Verlag Italia 2012

ANALYZE

Analyze is the third step in a Lean Six Sigma project roadmap. In this phase we try to:

- Explore the relationships among variables and start root cause analysis of major problems
- Conduct cause - effect analysis for trouble shooting
- Discover the real root causes rather than take care of symptoms
- Use statistical significance testing as a tool to identify key variables for response

Cause-Effect Diagram

Objective:

- The Cause-Effect Diagram is a visual tool that can help to identify the relationship between an **effect** and its possible **root causes**

- The Cause-Effect Diagram is also an effective tool for quality management and Brainstorming(G). It is one of the common tools for Lean Six Sigma projects and problem solving techniques

Cause-Effect Diagram

Why use the Cause-Effect Diagram?

- It is easy to understand and is a comprehensive graphic template that can logically display complex cause and effect relationships
- It can improve the understanding of a detailed relationship between cause and effect

When to use it:

- If there is a large number of possible root causes
- When the relationship between cause and effect is not clear

Lean6σ

Cause-Effect Diagram

How to build a Cause-Effect Diagram:

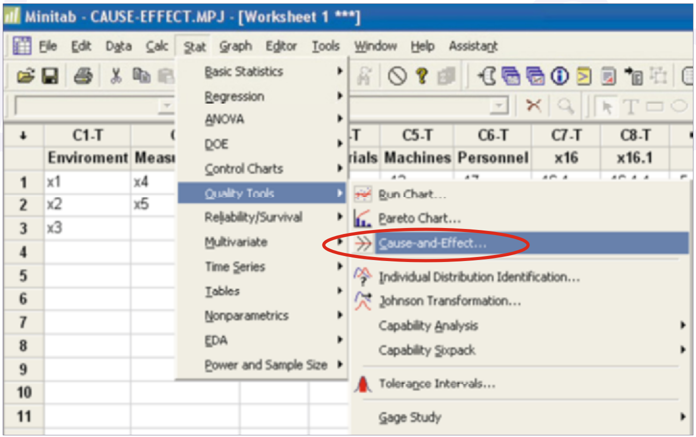
1. Define the problem and identify the effect to be analyzed
2. Identify the categories of possible root causes (commonly used categories: *Measurements, Machines, Man/Personnel, Materials, Methods, Mother Nature/Environment*)
3. Identify potential causes and group them into categories. The method of the ***5 Whys*** can be used to determine the exact relationship between causes and effect
4. Sort the causes according to the possible degree of influence towards the effect

Lean6σ

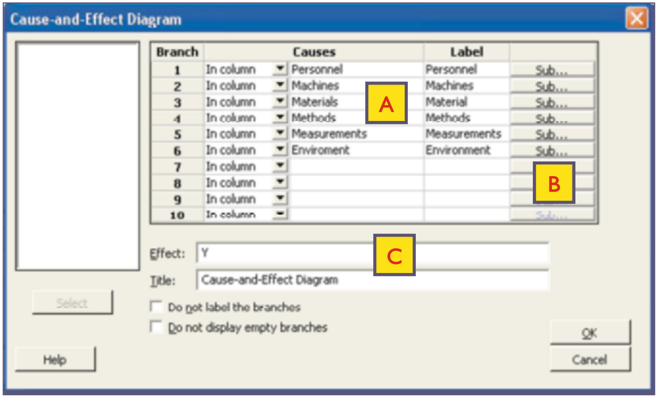
Cause-Effect Diagram

MINITAB:

Stat > Quality Tools > Cause-and-Effect…



Cause-Effect Diagram



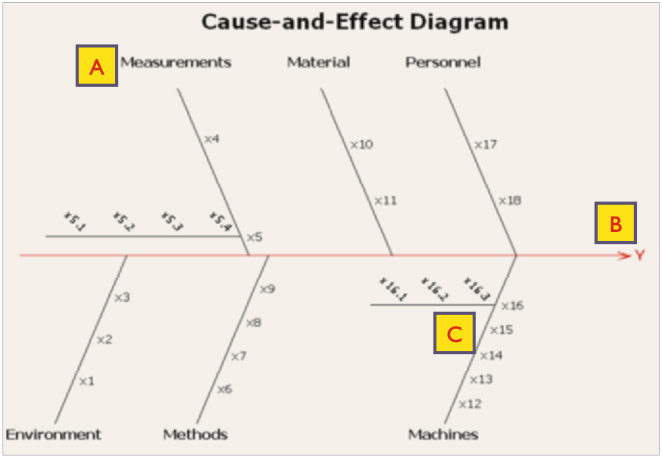
A Enter the columns that contain the main categories of causes

B Enter the columns that contain the secondary causes

C Enter the effect to be analyzed

Cause-Effect Diagram

MINITAB: Output



A

Main cause categories

B

Effect

C

Root causes drill down by 5 whys:

- Why Y happens? Because of Machine
- Why machine influences Y? Because X16
- Why X16 influences machine? Because X16.1 X16.2 e X16.3
- Why…

Statistical Hypothesis Testing

Objective:

- Statistical Hypothesis Testing is used to make an inference or conclusion for a population, starting from sample data observation

- Typical applications of Hypothesis Testing are:
  - the comparison of means between two or more groups
  - the comparison of variances between two or more groups
  - the comparison of proportions, also extracted from samples of different sizes

Statistical Hypothesis Testing

There are many types of hypothesis testing. We need to select the right Hypothesis Testing method for the right problem, as illustrated by the following table:

	HYPHOTESIS TESTING	PURPOSE
Mean comparison	1-Sample t	To compare means between a sample and a reference known mean
	2-Sample t	To compare means between two groups
	Paired t-TEST	To compare means between two groups when data are paired
	ANOVA (F TEST)	To compare means between more than two groups
Variance comparison	Variance Test	To compare variances between two or more groups
Proportion comparison	Chi- Square Test	To compare proportions between two or more groups

Hypothesis Testing: 1-Sample t

Objective:

- The 1-Sample t test compares the mean of a sample with a given value

Fundamental Assumptions:

- Data should be normally distributed

How to read the test result:

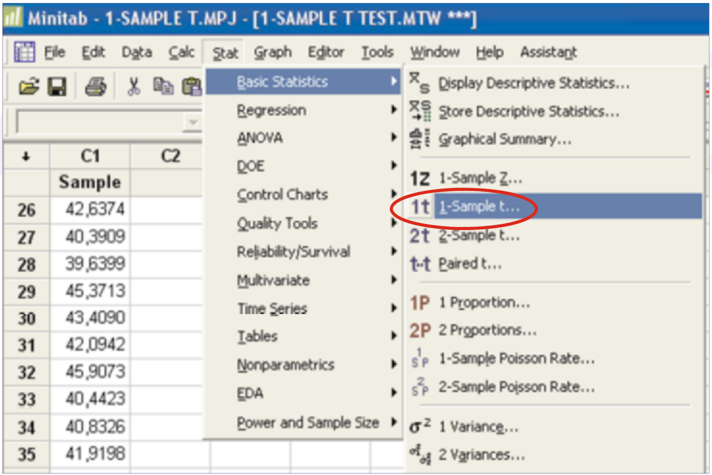
- It is based on P-Value

P-Value > 0.05	There is no significant difference between the population mean, from which the sample comes, and the given value
P-Value ≤ 0.05	The population mean is significantly different than the given value

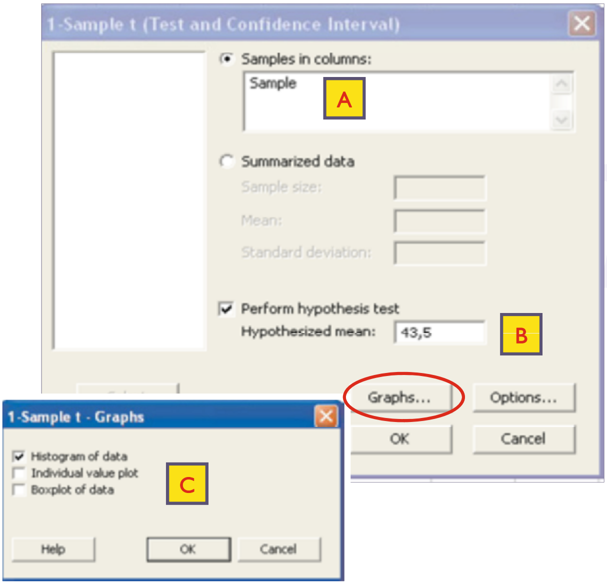
Hypothesis Testing: 1-Sample t

MINITAB:

Stat > Basic Statistic > 1-Sample t…



Hypothesis Testing: 1-Sample t



A

Enter the column that contains the sample data

B

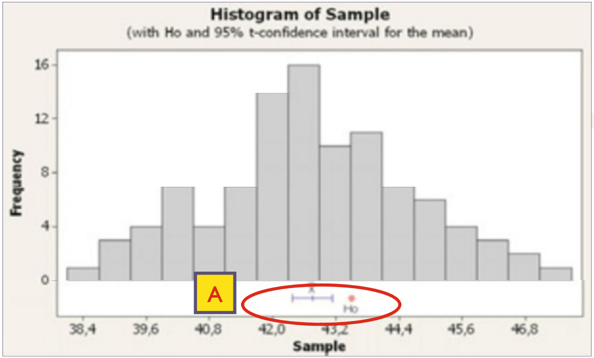
Enter the value that you want to compare with the mean

C

Choose additional graph to illustrate the result

Hypothesis Testing: 1-Sample t

MINITAB: Output




```
One-Sample T: Sample

Test of mu = 43,5 vs not = 43,5
```

Variable	N	Mean	StDev	SE Mean	95% CI	T	P
Sample	100	42,762	1,901	0,190	(42,384; 43,139)	-3,88	0,000

B

A

You can graphically observe if the Confidence Interval for the population mean contains the given reference value, if the interval doesn't contain the value, it indicates that population mean is not equal to the given value

B

With P-Value ≤ 0.05, it indicates that the population mean is statistically and significantly different than the given value

Hypothesis Testing: 2-Sample t

Objective:

- The 2-Sample t test compares the **means** of 2 populations

Fundamental Assumption:

- Data are normally distributed

How to read the test result:

- It is based on P-value

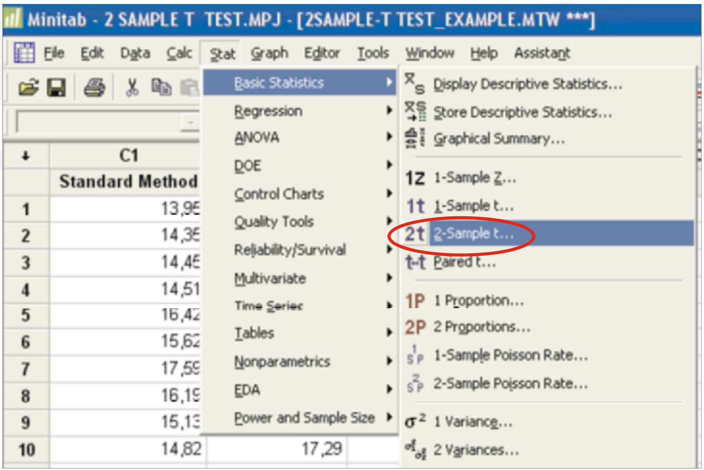
P-Value > 0.05	There is no statistically significant difference between the two population means
P-Value ≤ 0.05	The two population means are significantly different

Lean6σ

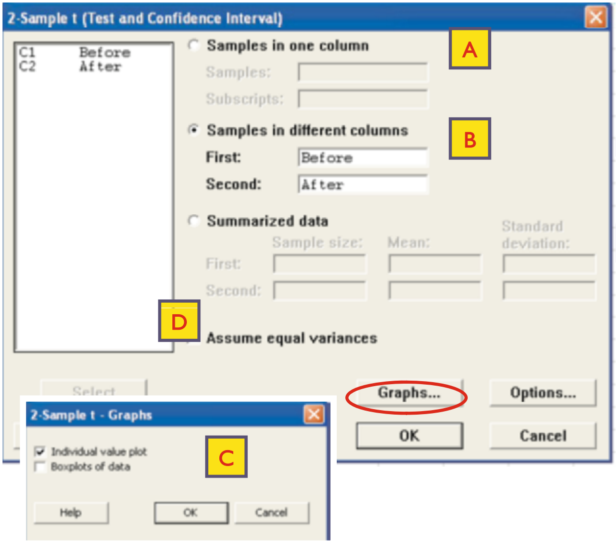
Hypothesis Testing: 2-Sample t

MINITAB:

Stat > Basic Statistic > 2-Sample t…



Hypothesis Testing: 2-Sample t



A Select this option if the two samples are arranged in one column

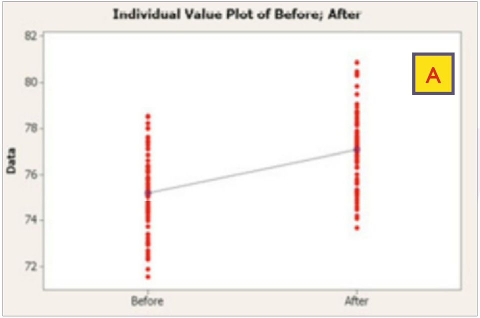
B Select this option if the two samples of data are in different columns

C Choose graphical display options

D Choose this option if two variances are tested to be the same (page 168)

Hypothesis Testing: 2-Sample t

MINITAB: Output



Two-Sample T-Test and CI: Before; After

```
Two-sample T for Before vs After

         N   Mean  StDev  SE Mean
Before  75  75.21   1.55     0.18
After   75  77.08   1.62     0.19

Difference = mu (Before) - mu (After)
Estimate for difference:  -1.874
95% CI for difference:  (-2.403; -1.344)
T-Test of difference = 0 (vs not =): T-Value = -6.99  P-Value = 0.000  DF = 147
```

B

A

It is visually possible to observe if two groups have equal means (two clusters of points will be at the same height if means are equal)

B

If the P value is less than 0.05, it indicates that two population means are statistically and significantly different

Hypothesis Testing: Paired t-Test

Objective:

- Paired t-Test is a hypothesis test that compares the **mean** differences of two related samples (**paired** samples). It is useful when we want to eliminate the presence of significant differences among sample members (person, machine, etc.) from the tests. For example, we can use Paired t-Test to compare the effects of two different machines (Machine A and B) on the same part
- The Paired t-Test would likely create tighter Confidence Intervals, because only the variation in paired difference is considered

Fundamental Assumptions:

- Two data sets have to be matched
- The distribution of the difference of data must be normal

Hypothesis Testing: Paired t-Test

Example of *paired* data collection:

C1	C2	C3	C4
Part	Measurement System1	Measurement System2	Difference in Measurement
1	10,4010	10,5100	-0,109041
2	10,6420	10,7230	-0,081006
3	10,2032	10,3200	-0,116827
4	11,2434	11,0900	0,153416
5	11,2198	11,3560	-0,136243
6	9,7822	10,0500	-0,267777
7	10,1403	10,1567	-0,016438
8	10,1583	10,4500	-0,291710
9	12,0665	11,9700	0,096516
10	10,5171	10,5200	-0,002857

How to read the test results:

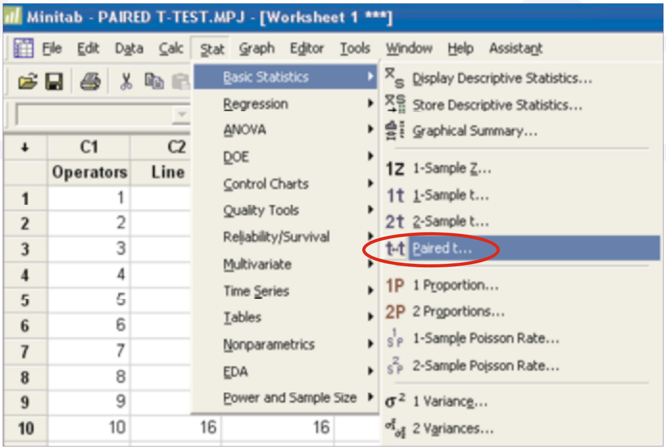
- The testing result is based on P-Value

P-Value > 0.05	There is no statistically significant difference for two matched data sets
P-Value ≤ 0.05	There is a statistically significant difference in two matched data sets

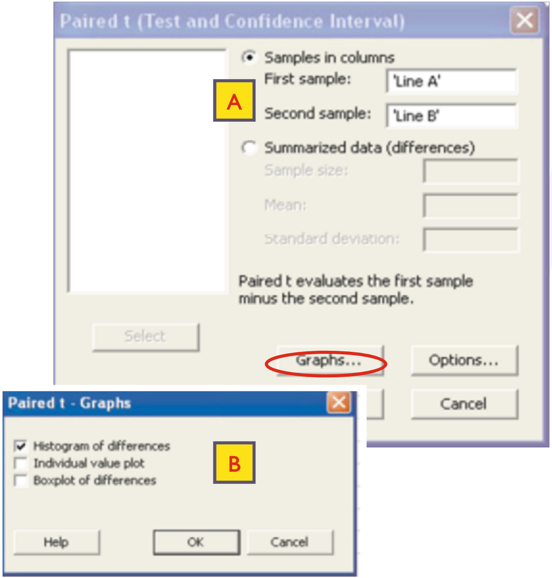
Hypothesis Testing: Paired t-Test

MINITAB:

Stat > Basic Statistic > Paired t…



Hypothesis Testing: Paired t-Test

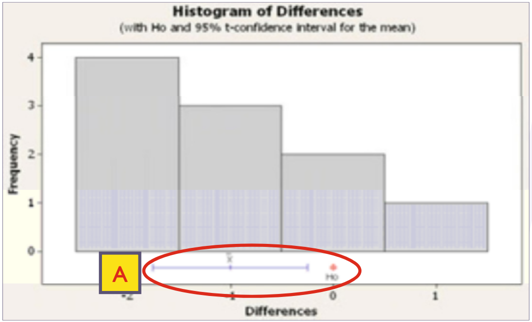


A Select this option (*samples in columns*) if two data sets are in different columns and select columns for two samples

B Select graphic display options for the test (e.g., select histogram of differences)

Hypothesis Testing: Paired t-Test

MINITAB: Output




```
Paired T-Test and CI: Line A; Line B

Paired T for Line A - Line B

             N    Mean   StDev  SE Mean
Line A      10  12,300   3,093    0,978
Line B      10  13,300   2,908    0,920
Difference  10  -1,000   1,054    0,333


95% CI for mean difference: (-1,754; -0,246)
T-Test of mean difference = 0 (vs not = 0): T-Value = -3,00  P-Value = 0,015
```

B

A

This graphic display is to check if the confidence interval contains zero. If yes, it indicates H_0 cannot be rejected i.e. there is no significant difference for two data pairs

B

If P-Value is ≤ 0.05, it indicates that two data pairs are statistically different

Hypothesis Testing: ANOVA

Objective:

- ANOVA is a Hypothesis Testing procedure that can compare the **means** of 2 or more groups
- ANOVA is also an analysis procedure that can perform key tests for other statistical methods such as Regressions and DOE

Fundamental Assumptions:*

- Data is normally distributed
- Variances are the same for all groups (page 168)

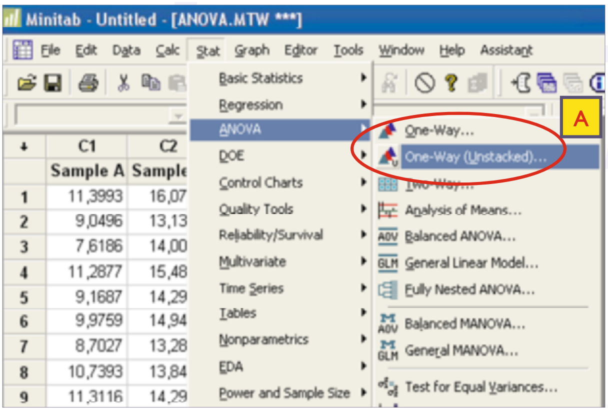
P-Value > 0.05	There is no significant differences among group means
P-Value ≤ 0.05	At least one group mean is significantly different than others

* Residuals analysis can be used to identify the goodness of the analytical model (also used in Regression, page186)

Hypothesis Testing: ANOVA

MINITAB:

Stat > ANOVA > One-Way…

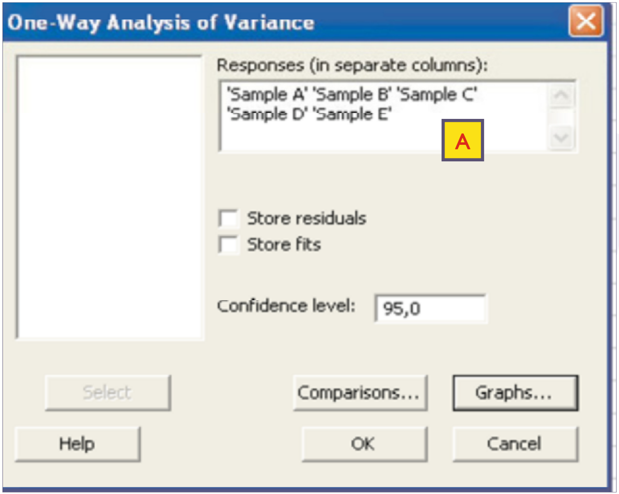


A

Select:

- *One Way (Unstacked).* When sample data are placed in different columns
- *One-Way.* When all sample data are placed in one column

Hypothesis Testing: ANOVA



A

Enter the response columns to be analyzed

Hypothesis Testing: ANOVA

MINITAB: Output

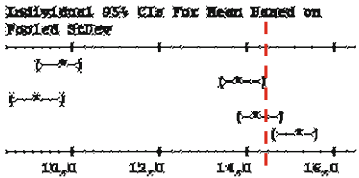
One-way ANOVA: Sample A; Sample B; Sample C; Sample D; Sample E

Source	DF	SS	MS	F	P
Factor	4	598,52	149,63	110,40	0,000
Error	100	135,05	1,35		
Total	104	733,57			

S = 1,162 R-Sq = 81,59% R-Sq(adj) = 80,85%

A

Level	N	Mean	StDev
Sample A	20	9,718	1,064
Sample B	20	13,821	1,410
Sample C	15	9,201	1,005
Sample D	25	14,235	1,218
Sample E	25	15,152	1,041



Pooled StDev = 1,162

B

A

When P-Value is ≤ 0.05, it indicates that at least one population mean is statistically and significantly different than others

B

Visually, overlapping Confidence Intervals (indicated by the red line crossing 3 groups) highlights there is no significant difference on means for these groups. Non-overlapping Confidence Intervals indicates significant differences

Hypothesis testing: Chi-Square

Objective:

- The Chi-Square test aims to compare proportions or frequencies of occurrences by several groups

Note:

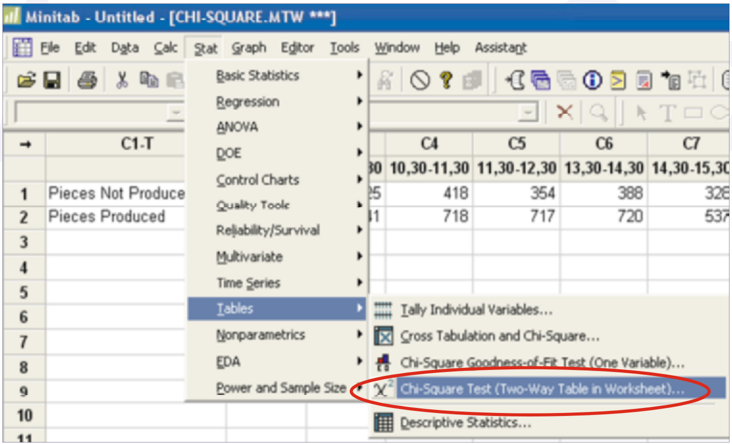
- Normal distribution of data is not required

P-Value > 0.05	There is no difference between the proportions (frequencies) of samples
P-Value ≤ 0.05	The proportion (frequencies) of at least one group is statistically different than others

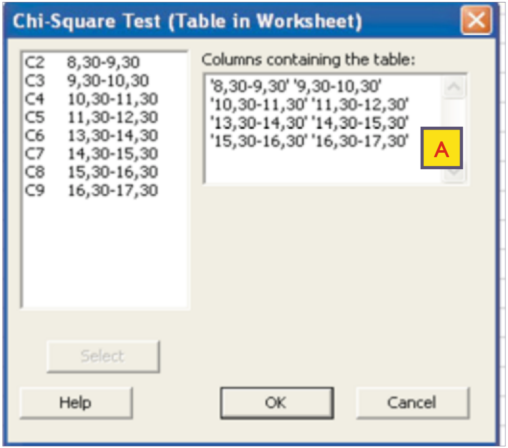
Hypothesis Testing: Chi-Square

MINITAB:

Stat > Tables > Chi-Square Test (Table in Worksheet)…



Hypothesis Testing: Chi-Square



A

Enter the columns containing the groups to compare

Hypothesis Testing: Chi-Square

MINITAB: Output

Chi-Square Test: 8,30-9,30; 9,30-10,30; 10,30-11,30; 11,30-12,30; 13,30-14,30;

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

        8,30-9,30  9,30-10,30  10,30-11,30  11,30-12,30  13,30-14,30
    1         378         325          418          354          388
           384,48      306,03       401,44       378,47       391,55
            0,109       1,176        0,683        1,582        0,032

    2         710         541          718          717          720
           703,52      559,97       734,56       692,53       716,45
            0,060       0,643        0,373        0,865        0,018

Total        1088         866         1136         1071         1108

        14,30-15,30  15,30-16,30  16,30-17,30  Total
    1           328          380          308   2879
             305,68       388,72       322,64
              1,630        0,196        0,664

    2           537          720          605   5268
             559,32       711,28       590,36
              0,891        0,107        0,363

Total           865         1100          913   8147

Chi-Sq = 9,392; DF = 7; P-Value = 0,226
```

A

A

Highlighted Items:

- The calculated Chi Square statistic value by the formula:

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

- P-Value $\leq$ 0.05 is needed to indicate statistical significance between groups. For example, P-Value of 0.226 indicates there is no significant differences among groups

Hypothesis Testing: Test for Equal Variances

Objective:

- This test compares Variances of several groups to determine if they are equal

Fundamental Assumptions:

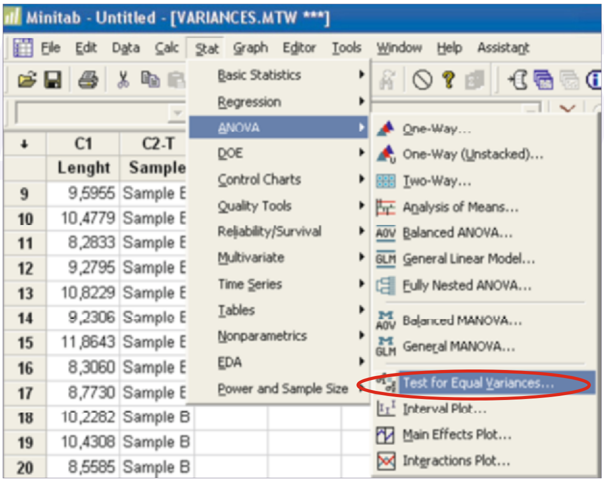
- It is necessary to choose the most appropriate method based on the distribution of data:
  - Normally distributed data → *F-Test* (for 2 samples) and *Bartlett's Test* (for more than 2 samples)
  - General continuous distribution → *Levene's Test*

P-Value > 0.05	There is no statistically significant difference on Variances of groups
P-Value ≤ 0.05	There is at least one group Variance that is significantly different from others

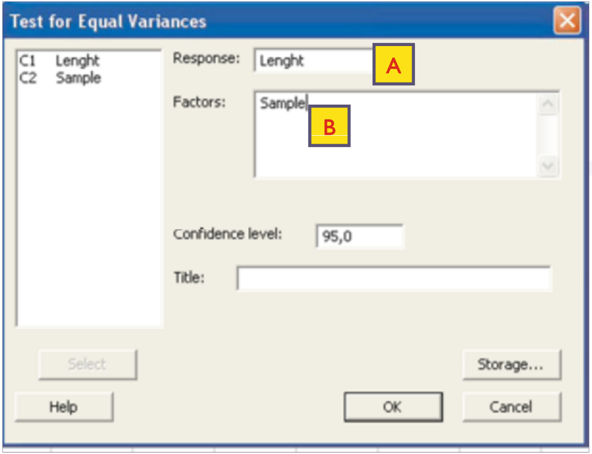
Hypothesis Testing: Test for Equal Variances

MINITAB:

Stat > Basic Statistics > Test for Equal Variances…



Hypothesis Testing: Test for Equal Variances



A Enter response variable

B Enter the columns containing the factors in the model

Hypothesis Testing: Test for Equal Variances

MINITAB: Output

Test for Equal Variances: Length versus Sample

95% Bonferroni confidence intervals for standard deviations

Sample	N	Lower	StDev	Upper
Sample A	20	0,923465	1,31594	2,19260
Sample B	20	0,875280	1,24728	2,07820
Sample C	15	0,729982	1,09183	2,02382
Sample D	20	0,763471	1,08795	1,81273
Sample E	20	0,482262	0,68723	1,14505

Bartlett's Test (Normal Distribution)
Test statistic = 8,14; p-value = 0,087

Levene's Test (Any Continuous Distribution)
Test statistic = 1,79; p-value = 0,139

A

Test for Equal Variances: Length versus Sample

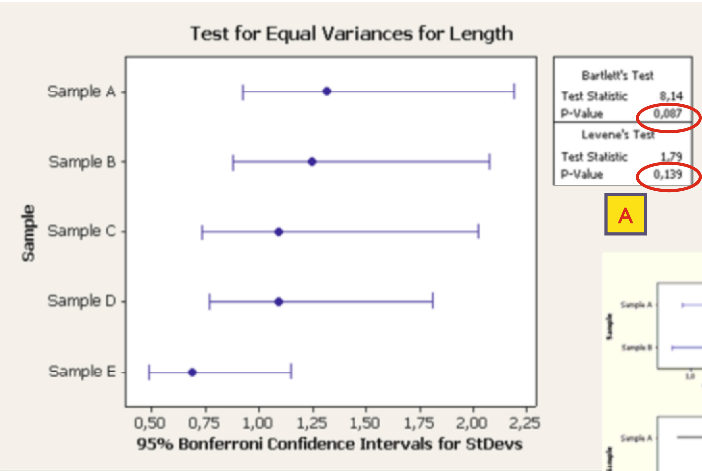
A

Minitab will choose F-Test or Bartlett's Test depending on the number of groups. We have to choose the right test (Bartlett or Levene) based on the distribution of data (normal or generic continuous distribution)

We need to see P-Value ≤ 0.05 in order to determine whether there is a significant difference in group variances

Hypothesis Testing: Test for Equal Variances

MINITAB: Output

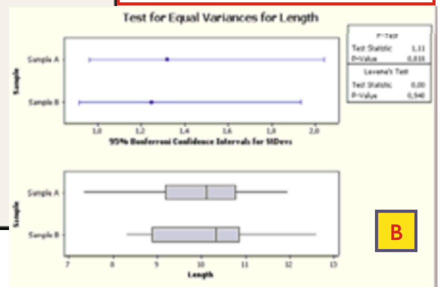


A

Minitab also gives graphical outputs, p-values and Confidence Intervals

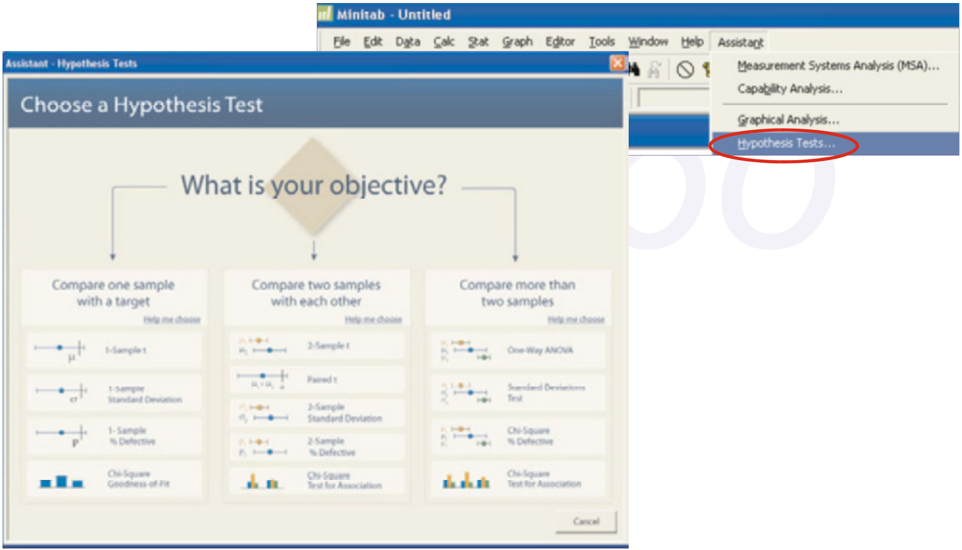
B

Minitab output in case of 2 samples analysis



Hypothesis Testing & Minitab

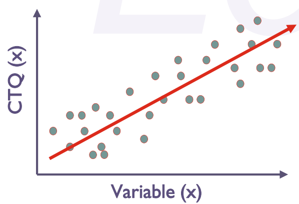
Minitab Assistant helps you to choose the right Hypothesis Testing:



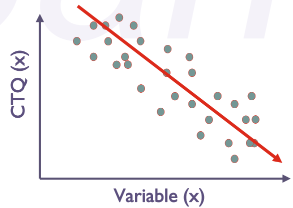
Scatter Diagram

Objective:

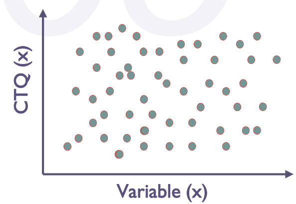
- *Scatter Diagram* is a graph that can be used to determine a possible correlation between a pair of input and output variables
- There are 3 possible situations:



Positive Correlation



Negative Correlation

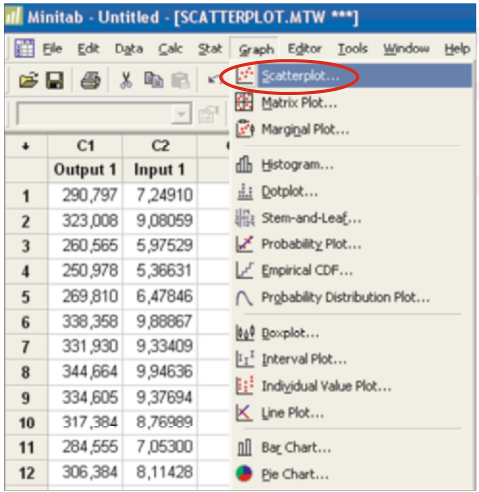


No Correlation

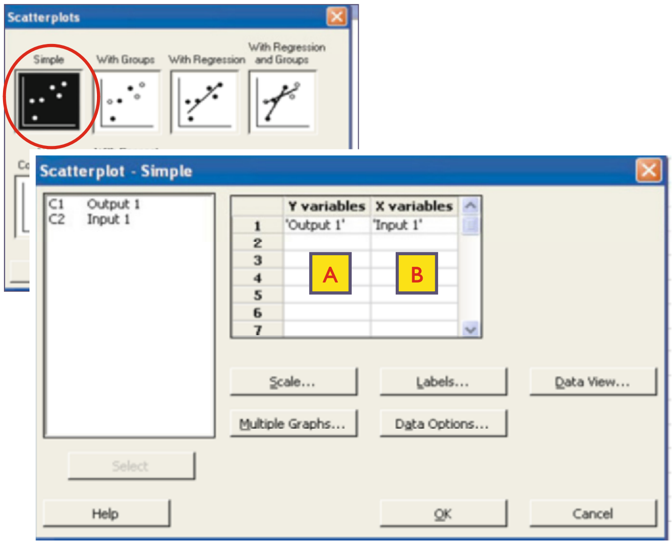
Scatter Diagram

MINITAB:

Graph> Scatterplot…



Scatter Diagram

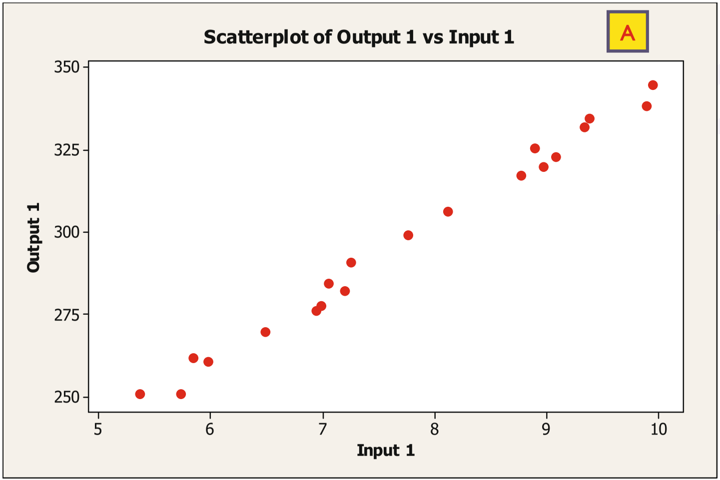


A Enter the column that contains output variable (Response or Y *variable*)

B Enter the column that contains input variable (*X variable*)

Scatter Diagram

MINITAB: Output



A

Scatter Diagram is a graphic plot that displays Input-Output data pairs in X-Y axes

This plot can be used to qualitatively observe if there is a dependency relationship between 2 variables (potential correlation)

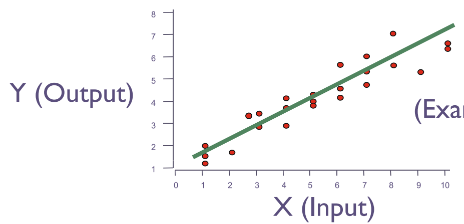
Regression: Fitted Line Plot

Objective:

- Regression is an analytical tool that can be used to establish, if it exists, a **mathematical model** between Input and Output variables (see Analytical Approach, page 183)

Fundamental Assumptions:

- Variable Y → Continuous
- Variable X → Continuous
- Residuals → random variable



(Example of Fitted Regression line)

Regression: Fitted Line Plot

- For a Fitted Regression model, there is a commonly used performance indicator that can measure how good this model fits the data
- This indicator, called R-Squared (R-Sq%, or R-Sq), tells you the percentage of variations in data (from 1% to 100%) that can be explained by the regression model and is calculated by:

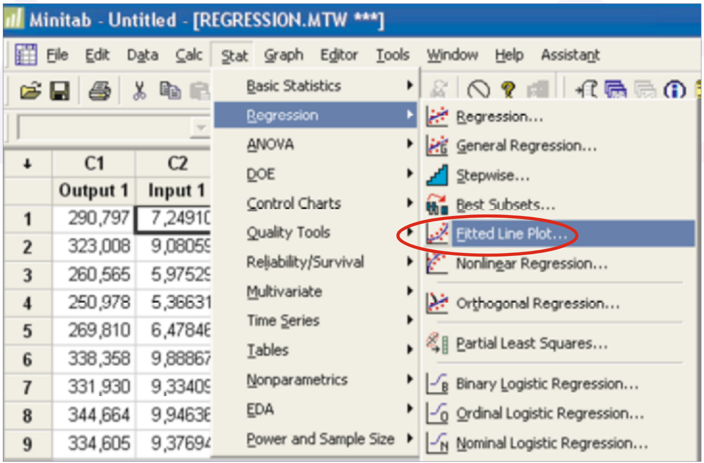
$$R\text{-}Sq = \frac{\text{explained variation}}{\text{total variation}}$$

R-Sq ≥ 70	The mathematical model explains the data correlation well
R-Sq < 70	The mathematical model doesn't explain the data correlation well

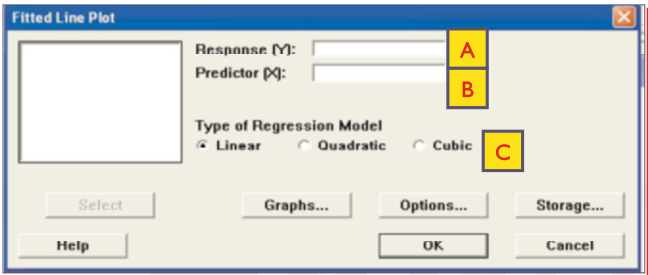
Regression: Fitted Line Plot

MINITAB:

Stat > Regression > Fitted Line Plot…



Regression: Fitted Line Plot

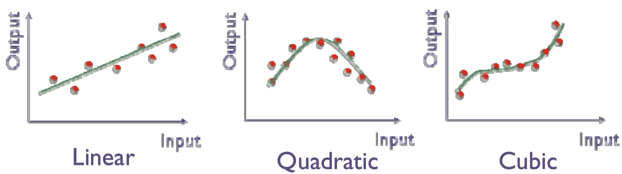


A Insert the column that contains Output (Y variable)

B Insert the column that contains Input (X variable)

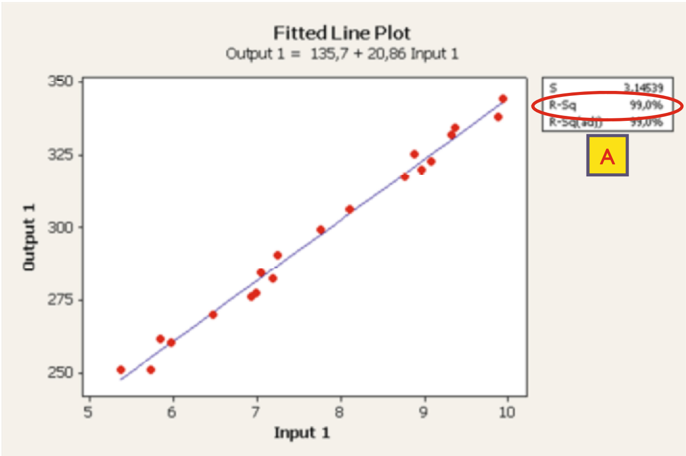
C Choose an appropriate model form (linear, quadratic, or cubic) for Regression. It may be useful to make a Scatter Diagram first to observe the pattern in data

Examples of fitted line plot, with different types of models:



Regression: Fitted Line Plot

MINITAB: Output



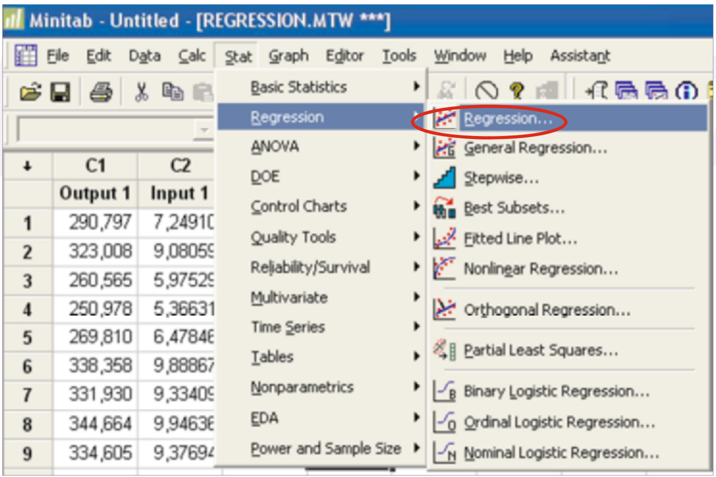
A

Minitab provides the graphical illustration of a Fitted Regression line model, a Scatter Diagram of all data as well as calculated R-squared value

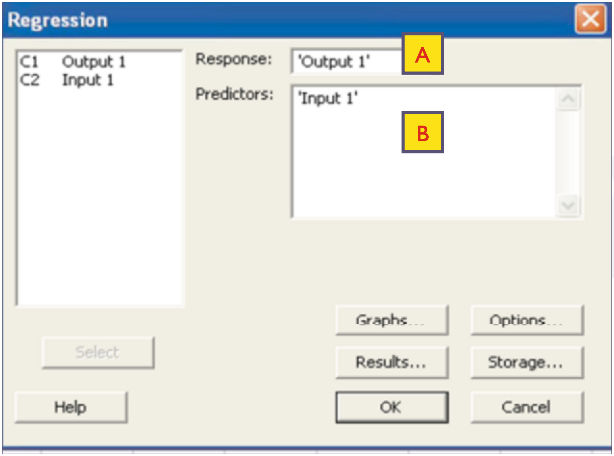
Regression: Analytical Approach

MINITAB:

Stat > Regression > Regression…



Regression: Analytical Approach



A

Insert the column that contains Output (Y variable)

B

Insert the column that contains Input (X variable)

Regression: Analytical Approach

MINITAB: Output

Regression Analysis: Output 1 versus Input 1

```
The regression equation is
Output 1 = 136 + 20,9 Input 1          A

Predictor      Coef   SE Coef      T      P
Constant    135,747     3,660  34,96  0,000
Input 1     20,8559    0,4926  42,34  0,000   B

S = 3,14539   R-Sq = 99,1%   R-Sq(adj) = 99,0%
                  C
Analysis of Variance

Source          DF     SS     MS        F      P
Regression       1  17736  17736  1792,66  0,000
Residual Error  18    178     10
Total           19  17914                    D
```

A

Explicit Linear Regression equation with estimated coefficients

B

Significance tests of coefficients. If P-Value is ≤ 0.05, then the predictors are significant

C

R-sq value is calculated, and indicates how well the Regression model fits the data

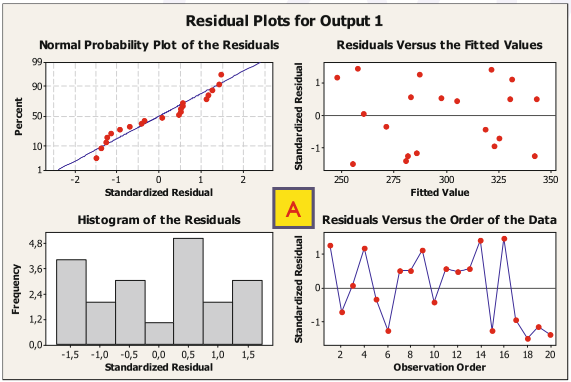
D

In this test, if P-Value is ≤ 0.05 then it indicates that the Regression relationship is significant

Regression: Assumptions

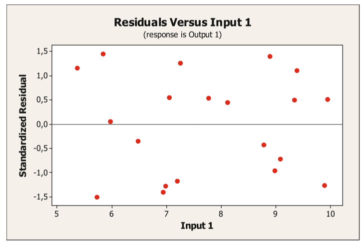
Residual analysis (also applicable for Fitted Line Plot):

- Residuals not be related to X
- Residuals should be independent of time
- Residuals should be near constant regardless of predicted Y values
- Residuals should be normally distributed



A

Minitab generates 4 graphs to verify these four assumptions



IMPROVE

Arcidiacono G., Calabrese C., Yang K.: Leading processes to lead companies: Lean Six Sigma.
DOI 10-1007/978-88-470-2492-2, © Springer-Verlag Italia 2012

IMPROVE

The *Improve* phase is the fourth step of the DMAIC Lean Six Sigma roadmap. In this step the existing process will be changed and optimized:

- This process optimization will be based on sound data analysis, a thorough understanding of the relationship between key process responses/performance metrics and key process variables, so this process optimization will be more likely to achieve real results backed by statistical confidence
- The improvement will take into account Lean applications, typical of Lean methodology and mindset, in order to reduce waste and to increase process efficiency
- The process optimization is based on scientific approach, real and accurate data. It is not based on subjective judgments

Lean6σ

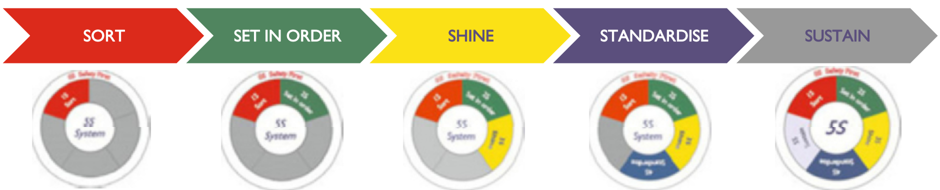
5S Program

Objective:

- The “5S Program” is a system for creating and maintaining a work environment clean, orderly, efficient and safe. The benefits of this method can be evaluated in terms of Quality, Safety and Productivity:

Productivity	Safety	Quality
• Eliminate wastes of time looking for equipment or items necessary for the job • Reduce cycle times • Maintain efficient equipment through proper maintenance and cleaning	• Reduce the likelihood of accident • Making the workplace more ergonomic and comfortable	• Eliminate the possibility of using parts previously discarded • Eliminate the possibility of using inappropriate tools

Overview:



5S Program

STEP 5S	OBJECTIVE	PRACTICAL NOTES
SORT	Identify what is needed and what is not needed in the workplace. Eliminate or segregate what is not necessary	Try to answer these questions: What is the use of this object? Why do I have it? How often is it used?
SET IN ORDER	Organize and arrange everything you need in the workplace so it can be quickly found, used and stored	Place all necessary items in the best possible location, at the "point of use" Use the 'visual' area approach (standard and not standard must be easily identified) Use labels and boards to make clear the inventory, equipment and other items so that everybody can understand the workplace
SHINE	Clean and maintain order in the workplace, equipment, floors into the shopfloor/office	Clean inside, under, over and around machinery and furniture. The cleaning of machine is a very important point because it can help prevent damage before it happens
STANDARDISE	Maintain and improve the standard of the first 3S	Introduce changes to the workstations that make cleaning and removal of dirt at the root easy and quick Use checklist to perform daily tasks of cleaning, maintenance and organization Identify areas and responsibilities
SUSTAIN	Make the standard 5S a daily habit and part of everyday work	Strengthen the workstation habits according to the 5S approach. Use audits with a "Steering Team" and relative corrective actions. Continuous improvement of 5S Use, if necessary, the OPL (One Point Lesson) and information board

5S Program

How to conduct a 5S event in practical steps:

1. Identify the area where the 5S system (production, warehouse, shipping, quality, laboratory) is implemented
2. Divide the area into zones and related people in charge
3. Define a *Steering Team**
4. Define roles of area responsible
5. Identify Steering Team responsibilities
6. Define the 5S Checklist and audit standard format
7. Establish the terms and timetable for implementing audit
8. Implement the 5S information board

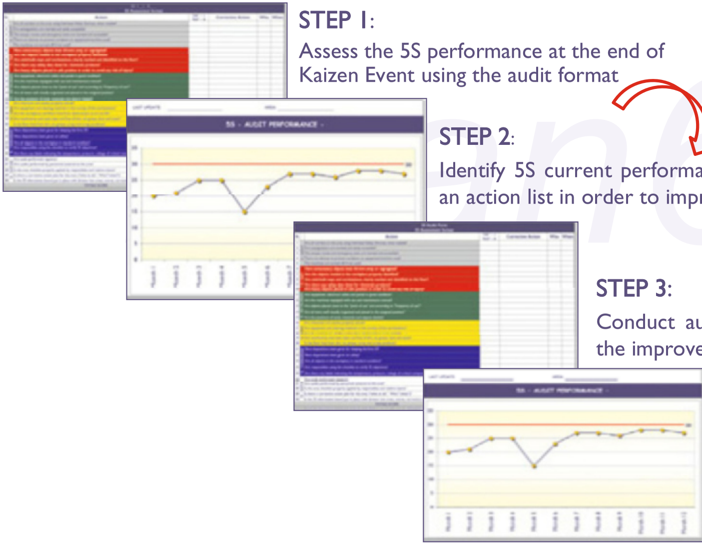
* See the examples of format in Kaizen standard form session (page 310)

5S Program


0S Safety First
1S Sort
2S Set in order
3S Shine
4S Standardise
5S Sustain
5S
5S Information Board

5S Program

How to measure 5S performance:



STEP 1:

Assess the 5S performance at the end of Kaizen Event using the audit format

STEP 2:

Identify 5S current performance and plan an action list in order to improve it

STEP 3:

Conduct audit in order to detect the improvement effectiveness

STEP 4:

Go to Step 2…

5S Program

Some tips before getting started:

- For the success of 5S implementation go through employee involvement
- Make sure that employees understand the 5S system and why it is so important for them and for the company
- Start with a pilot phase and then extend the approach to other areas
- It is necessary in the first phase of implementation for everyone to sacrifice and appreciate the real benefits of the approach
- The manager should sponsor the activity
- Make responsibilities clear and understood by everybody
- Make the process as visual as possible
- Link the 5S program to all other Kaizen activities (e.g. Standard Work, SMED, TPM, Six Sigma projects etc.)
- If possible, integrate the 5S program with safety program

Standard Work

Objective:

- Standard Work [(G)] is the most effective combination of manpower, materials and machinery to produce something in the time, quality and quantity required by the customer. This is done through continuous observation and improvement of the workplace. Standard Work is characterized by three main elements: Takt Time; Standard Work in process and Work sequence

Definition:

- **Standard Work in process**: The minimum work-in-process needed to maintain Standard Work. Standard WIP can be parts completed and in the machine after auto cycle, parts placed in equipment with cycle times bigger than Takt Time, and parts handled by the operators on the production line
- **Work sequence**: The sequence of steps and activities that need to be performed in order to complete the production process
- **Takt Time** (see page 120)

Lean6σ

Standard Work

Step 1: analyze the operator Cycle Time

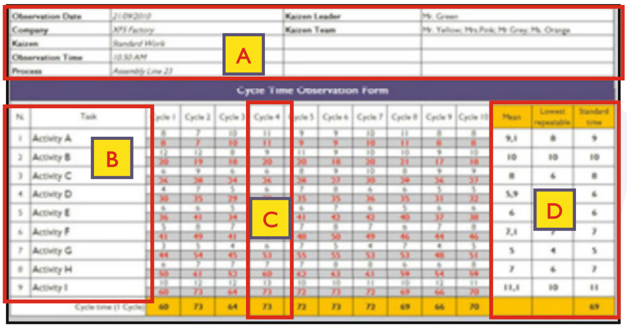
Observation Date	21/09/2010	Kaizen Leader	Mr. Green
Company	XFS Factory	Kaizen Team	Mr. Yellow; Mrs.Pink; Mr Grey; Ms. Orange
Kaizen	Standard Work		
Observation Time	10.50 AM		
Process	Assembly Line 23		

Cycle Time Observation Form

N.	Task	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Mean	Lowest repeatable	Standard time
1	Activity A	8	7	10	11	9	9	10	11	8	8	9,1	8	9
		8	7	10	11	9	9	10	11	8	8			
2	Activity B	12	12	8	9	11	9	10	10	9	10	10	10	10
		20	19	18	20	20	18	20	21	17	18			
3	Activity C	6	9	6	6	8	9	10	8	9	9	8	6	8
		26	28	24	26	28	27	30	29	26	27			
4	Activity D	4	7	5	6	7	8	6	6	5	5	5,9	5	6
		30	35	29	32	35	35	36	35	31	32			
5	Activity E	6	6	5	7	6	7	6	5	6	6	6	6	6
		36	41	34	39	41	42	42	40	37	38			
6	Activity F	5	8	7	8	7	8	7	6	7	8	7,1	7	7
		41	49	41	47	48	50	49	46	44	46			
7	Activity G	3	5	4	6	7	5	4	7	4	5	5	4	5
		44	54	45	53	55	55	53	53	48	51			
8	Activity H	6	7	7	7	7	8	8	6	6	8	7	6	7
		50	61	52	60	62	63	61	59	54	59			
9	Activity I	10	12	12	13	10	10	11	10	12	11	11,1	10	11
		60	73	64	73	72	73	72	69	66	70			
	Cycle time (1 Cycle)	60	73	64	73	72	73	72	69	66	70			69

Standard Work

Step 1: analyze the operator Cycle Time



- Each task must be between 5 and 10 s
- Document the complete sequence of the operator
- Generally, in order to have a robust time, it is necessary to repeat the measurement from 7 to 10 times
- Use the chronometer and teach the operators how to measure by themselves
- During measurement try to identify potential improvements

A

Define the activity and the team involved in it

B

Identify the main tasks to complete a cycle

C

Measure, where possible, one entire cycle recording the single task time and the cumulative time

D

For each task identify mean and lowest repeatable performance. The time will be equal to the mean if the lowest repeatable is smaller than mean

Standard Work

Step 2: understand the relation between Cycle Time and Takt Time

$$\text{TAKT TIME} = \frac{\text{Available Time (Time)}}{\text{Customer Demand (pcs/Time)}}$$

$$\text{N Operators necessary} = \frac{\text{Cycle Time}}{\text{Takt Time}}$$ A

Available Time: Total available time minus planned downtime (example: Breaks)

Customer Demand: Total expected demand from Customer (pieces per unit of time)

Cycle Time: Total manual working time for one cycle (Touch Time) plus automatic run time. In case of production mix, the weighted mean (weighted on quantity) can be useful

A

CAUTION (LEAN METHODOLOGY BASIC CONCEPT):

Customer demand increase → Takt Time Decrease (increment of speed rate) → No. Operator needed increase

Customer demand decrease → Takt Time Increase (reduction of speed rate) → No. Operator needed decrease

Standard Work

Step 3: measure machine process capacity

Observation Date	*21.09.2010*	Opearting time per shift	27600 s
Company	*XFS Factory*	Shift No	1
Part No	*Cylinder*	Daily demand	400 pieces
Process	*Assembly Line 23*	Supervisor	Mrs. Brown

Process Capacity Form

Step #	Process Description	Machine	Base Time		Tool Change			Total Time (s)	Processing Capacity	Remarks
			Manual Time (s)	Machine Time (s)	# Pieces /Change	Change Time	Tool Change Time (s)			
1	Press	HL 345	3	15	100	180	1,8	19,8	1394	
2	Drilling	D10	6	65	70	200	2,9	73,9	374	Maximum capacity 374 pieces
3	Testing	TEST3	5	45	150	300	2,0	52,0	531	
		Total:	14					Maximum daily production:	374	

Standard Work

Step 3: measure machine process capacity

Observation Date	*21.09.2010*	Opearting time per shift	27600 s
Company	*XFS Factory*	Shift No	1
Part No	*Cylinder*	Daily demand	400 pieces
Process	*Assembly Line 23*	Supervisor	Mrs. Brown

Process Capacity Form

Step #	Process Description	Machine	Base Time		Tool Change			Total Time (s)	Processing Capacity	Remarks
			Manual Time (s)	Machine Time (s)	# Pieces /Change	Change Time	Tool Change Time (s)			
1	Press	HL 345	3	15	100	180	1,8	19,8	1394	
	Drilling	D10	6	65	70	200	2,9	73,9	374	Maximum capacity 374 pieces
	Testing	TEST3	5	45	150		2,0	52,0	531	
		Total:	14				Maximum daily production:		374	

- The capacity sheet is used to highlight machine capacity
- Identifies process bottlenecks: in the example Drilling Process has a maximum capacity of 374 pieces. At a daily demand of 400 pieces the machine is not capable of reaching customer needs
- Use one worksheet for each cell

A

Identify machine process during the cycle

B

For each cycle, identify machine cycle time. Manual contribution and pieces change time to calculate one process cycle time

C

Calculate machine capacity as the ratio of operating time per shift and total time for each machine; example:
- Press Total Cycle time = 19.8 s
- Operating time = 27600 s
- Maximum capacity = 1394 pieces

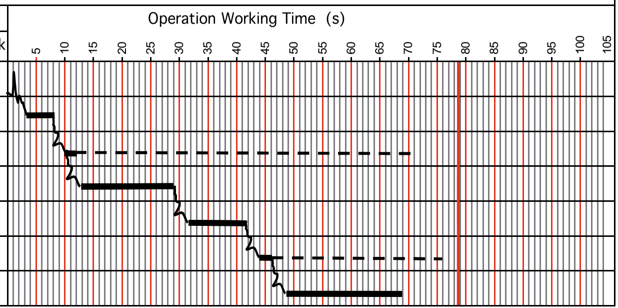
Standard Work

Step 4: analyze interaction between operator and equipment

Observation Date	*21.09.2010*	Opearting time per shift	27600 s	= Machine
Company	*XFS Factory*	Daily demand	400 pieces	= Manual
Part No	*Cylinder*	Takt Time (s)	69	= Walking
Process	*Assembly Line 23*	Supervisor	Mrs. Brown	= Takt Time

Standard Work Combination Form

Step #	Task/Activity Description	Time: Man.	Time: Auto	Time: Walk
1	Activity 1			3
2	Activity 2	5		2
3	Activity 3	2	60	3
4	Activity 4	15		3
5	Activity 5	10		2
6	Activity 6	2	30	2
7	Activity 7	20		



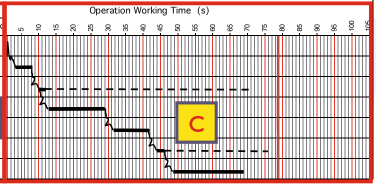
Standard Work

Step 4: analyze interaction between operator and equipment

Observation Date	*21.09.2010*	Opearting time per shift	27600 s	- - - = Machine
Company	*XFS Factory*	Daily demand	400 pieces	▬ = Manual
Part No	*Cylinder*	Takt Time (s)	69	∿ = Walking
Process	*Assembly Line 23*	Supervisor	Mrs. Brown	—— = Takt Time

Standard Work Combination Form

Step #	Task/Activity Description	Time Man.	Time Auto	Time Walk
1	Activity 1			3
2	Activity 2	5		2
3	Activity 3	2	60	3
4	Activity 4	15		
5	Activity 5	10		
6	Activity 6	2	30	2
7	Activity 7	20		



A B

- The Standard Work combination sheet could be a good starting point for improvement identification
- Combines Man and equipment interactions
- Identifies the relation between Takt Time and process Cycle Time
- It could be useful to have one sheet for each operator

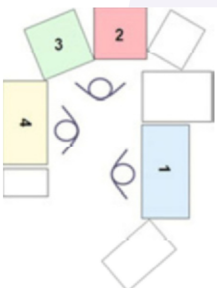
A Identify the main steps (task/activity) necessary to complete one cycle

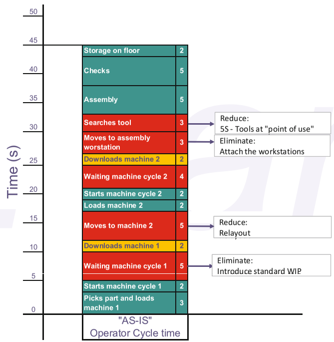
B Identify for each step the operator, machine and walk time contribution

C Identify on the sheet the operator steps, machine phases and walk steps. Highlight the Takt Time line

Standard Work

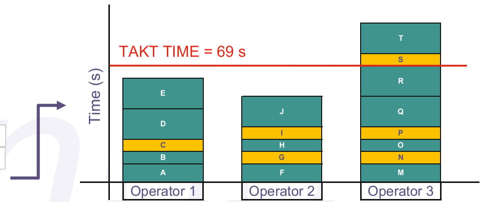
Step 5: map operator workload and make comparison with Takt Time



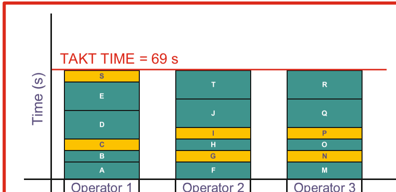


For each operator map the "as-is" workload

Determine the workload distribution for all the cell operators



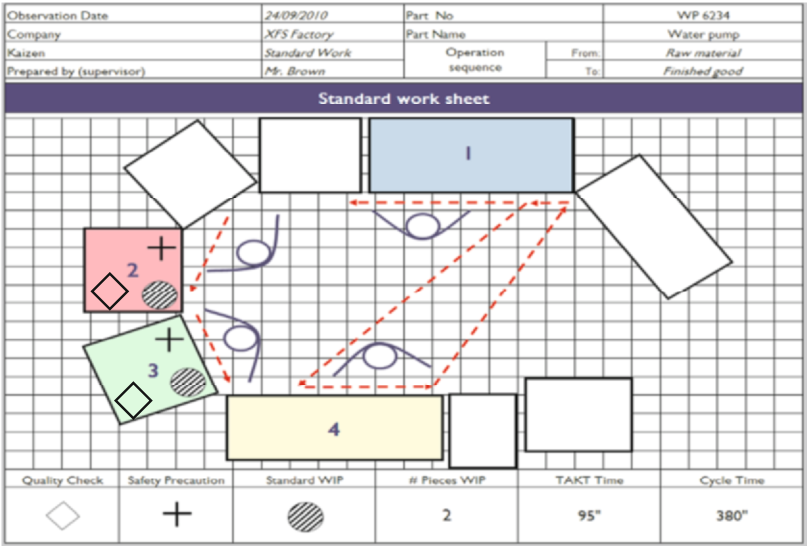
Compare operator workloads with Takt Time



Balance operators' workload in order to reach the Takt Time rhythm

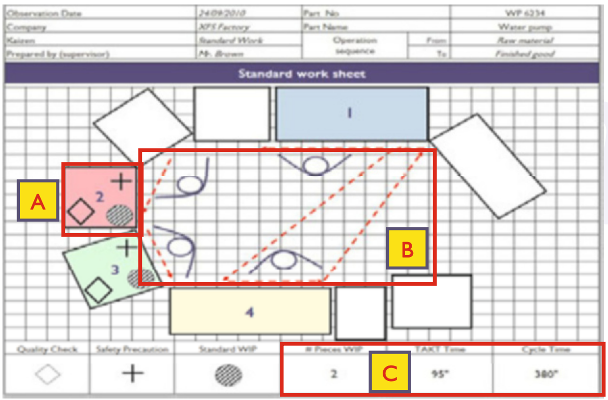
Standard Work

Step 6: prepare Standard Work sequence configuration according to Takt Time



Standard Work

Step 6: prepare Standard Work sequence configuration according to Takt Time



- It could be useful to have one sheet for each configuration of the cell
- Involve the team during sheet preparation

A

For each workstation identify Standard Work-in-process (the minimum work-in-process needed to maintain Standard Work), safety precautions and quality control

B

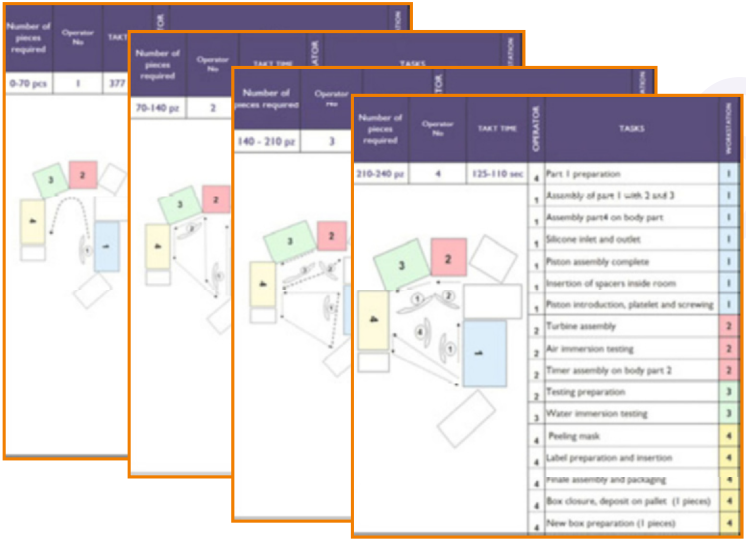
In this part of the sheet, highlight the movements of the operators involved in the process

C

The configuration identifies:
- No. Pieces WIP (in the example = 2)
- Takt Time (in the example = 95")
- Cycle time (in the example = 380")

Standard Work

Step 7: balance workload according to Customer Demand



- For each Takt Time the configuration should change
- Identify work sequence to have balanced operator workload
- Create the "playbook", the collection of different configurations
- The playbook should be placed next to the workstation so that operators can read the work sequence when necessary

Standard Work

Japanese experience:

- At the beginning of the 20th century, especially in the USA, industrial engineers designed and implemented the standards of work, which often caused tense labor-management relationships. After the 1950s, in Japan, work standards were run by "quality circles" and constantly improved and revised by workers. This practice was proven to be very effective and empowering (Imai, 1997)

Features of a good Standard Work (Imai, 1997):

1. Standards are the best, easiest, and safest way to do a job
2. They preserve know-how and expertise. Years of experience and knowledge can be lost by the loss of employees
3. They provide a way to measure performance
4. Correct standards show the relationship between cause and effect, leading to desired effects
5. Standards provide a basis for maintenance and improvement
6. They provide a set of visual signs on how to do the job
7. Standards are a basis for training
8. They are a basis for auditing
9. They are a mean to prevent recurrence of errors
10. Standards minimize variability

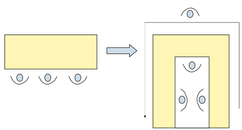
Cell Design

What is a "Cell":

- A "Cell(G)" is a workplace in which equipment, people, machinery, materials and methods are arranged to have a continuous production flow (Continuous Flow). It allows the "One piece flow" principle: an operator can process the entire product from beginning to end without interruption. The cell generally runs for a family of products. A typical configuration is the "U" shape.

Overview:

From traditional line to CELL DESIGN

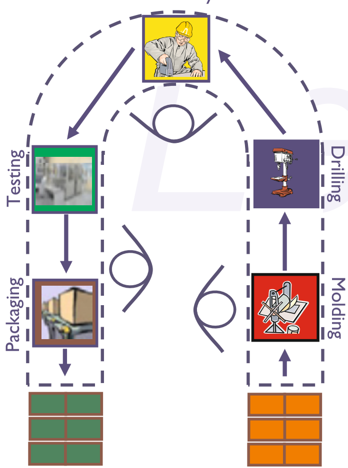


Full-size cardboard cutouts

Cell Layout example

Cell Design

U shape cell advantages:



- Allows a better balance of workload
- Promotes Visual Management approach
- Reduces movements along the line
- Improves communication
- Allows multi-processing
- Identifies abnormalities easily
- Does not interrupt the production inside the cell through the supply of materials from outside, thanks to "water spider"
- More flexibility in changing the Takt rhythm

Cell Design

How to implement a “cell”? Follow the operating steps below:

- Categorize products in “Product Family”
- Determine Takt Time for each family (using, if necessary weighted mean)
- Make a study of the elementary steps and relative times
- Workload balance and Standard Work
- Design the “U” shape cell in terms of:
  - Layout & workstation
  - Number of operators necessary to reach customer demand
  - Movements
  - Materials management and Standard WIP
- Simulate, where necessary, the cell with full-size cardboard cut-outs
- Cell implementation
- Set performance and relative goals for the cell designed
- Establish a continuous improvement approach … (*perfection*)

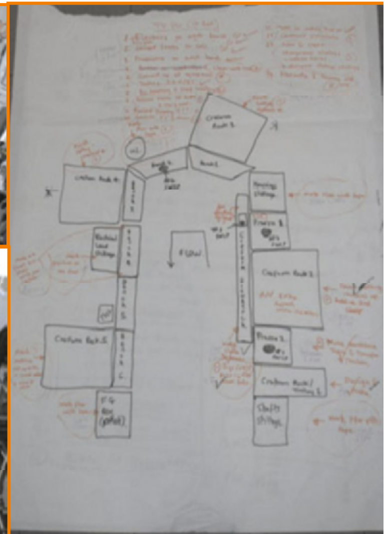
Cell Design

Practical tips during cell design and implementation:

- Tools and materials should be located where needed ("Point Of Use")
- During cell design think about the reduction of walking distance
- Reduce unnecessary movements
- Materials must be in front of the workstation
- Use "Safety first" approach (the workplace must be safe and ergonomic)
- Materials supply should be simple and immediate
- Use 5S and Visual Management

Cell Design

Example of cell and cell management:



SMED - Single Minute Exchange of Die

Objective:

- The Single Minute Exchange of Die (SMED) is a method that aims to reduce the changeover time of machine equipment, or in general a production/service process

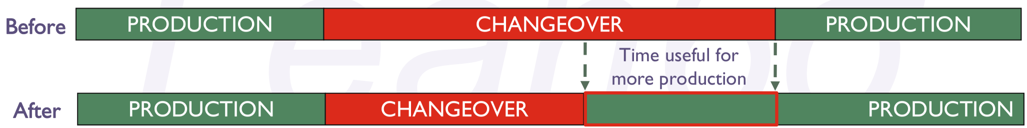
Definition:

- **Changeover time:** it is the time required to prepare a device, machine, process, or system from the last piece of the previous batch to the first good piece of the next batch

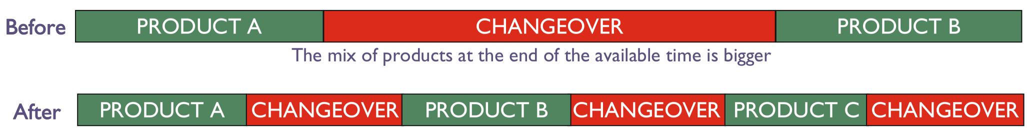
SMED - Single Minute Exchange of Die

When to use it:

- **Capacity problem:** it is necessary to reduce the changeover time in order to gain time available for production:



- **Need flexibility:** if the changeover time decreases the batch size can be smaller and consequently the flexibility of production can increase:



SMED - Single Minute Exchange of Die

How to perform a SMED activity:

1. Analyze actual procedure and elementary steps to realize the changeover (use a videotape if possible, especially in multi-person changeover)
2. Establish goals (WIP; batch size; changeover time reduction, etc.)
3. Apply the general procedure for set-up reduction (see next page)
4. Perform a test to validate the new set-up procedure
5. Identify new improvement opportunities
6. Create a new standard operating procedure

CAUTION: Definition of external and internal activity

EXTERNAL ACTIVITY: Activity that can be performed when the machine/process is running
INTERNAL ACTIVITY: Activity that can be performed only when the machine/process is stopped

SMED - Single Minute Exchange of Die

How to apply the general procedure:

STEP 0
STARTING STANDARD PROCEDURE

STEP 1
ANALYZE IN THE CHANGEOVER STEPS WHICH ACTIVITIES CAN BE CONSIDERED INTERNAL AND WHICH EXTERNAL

STEP 2
MOVE THE EXTERNAL ACTIVITY BEFORE OR AFTER THE CHANGEOVER TIME

STEP 3
VERIFY IF IT IS POSSIBLE TO TRANSFORM SOME INTERNAL ACTIVITIES INTO EXTERNAL ACTIVITIES

STEP 4
TRANSFORM THE INTERNAL ACTIVITIES INTO EXTERNAL AND MOVE OUTSIDE THE CHANGEOVER

STEP 5
OPTIMIZED INTERNAL ACTIVITY (simplify, reduce, eliminate adjustments)

STEP 6
REDUCE THE EXTERNAL ACTIVITIES

New optimized Changeover Procedure

SMED - Single Minute Exchange of Die

How to collect data according to changeover activities:

Observation Date	15/04/2010
Company	XYZ Company
Place	XXX
Kaizen	SMED
Kaizen Leader	Mr. Pink
Kaizen Team	Mr. Yellow; Mrs.Pink; Mr Grey; Ms. Orange
Last update	15/04/2010

Changeover Observation Form - 2 Operators

N.	Activity	Who	I / E	Activity	Who	I / E	Time	Tool	Possible ideas or Improvements
1	MACHINE STOP	Op.1	Internal	MACHINE STOP			0' 00"		
2	Open gate	Op.1	Internal				0' 50"		
3	Cut coils	Op.1	Internal				1' 14"	Scissor	Which is the right position for scissors? (EHS)_5S
4	Passes behind	Op.1	External				1' 22"		
5	Set the machine in manual configuration	Op.1	Internal				1' 31"		
6	Rewinds coils	Op.1	External				3' 24"		
7	Move the reel in order to put on the cradle	Op.1	Internal				3' 40"		
8	He goes to the desk to take the key	Op.1	External				4' 48"		
9	Raise the cradle (not high enough)	Op.1	Internal				6' 40"	Key	The thickness should be placed first on
10	Try to download the coil on the cradle	Op.1	Internal	Takes the forklift	Op.2	External	7' 15"		
10	Removes the tail of coil	Op.1	External	Lifts fork	Op.2	External	8' 28"		
11	Parades reel	Op.1	Internal	He goes to pick up the new coil near the crane	Op.2	External	9' 14"		
12	Puts the thickness on the cadle	Op.1	Internal	Descends from the forklift	Op.2	External	11' 11"		
13	Close the gate	Op.1	Internal	Goes to the crane and take remote control	Op.2	External	11' 14"		NVA
14	Restart the machine	Op.1	Internal	Guides the crane	Op.2	External	11' 40"		
15	Molding of the last remaining pieces of the coil	Op.1	Internal	Leads the hook near the new coil	Op.2	External	12' 23"		
16	He puts the pieces on the pallet	Op.1	Internal	He puts the hook on coil storaged on the cradle	Op.2	External	12' 45"		
17	Removed ground plane from the press	Op.1	Internal	Positioning with crane of the coil in the middle of the way	Op.2	External	13' 05"		
18	Puts it next to the molds supermarket	Op.1	Internal	Turns the coil for correct positioning	Op.2	External	14' 00"		
...	...	...	...	...	...	...	...	...	.....

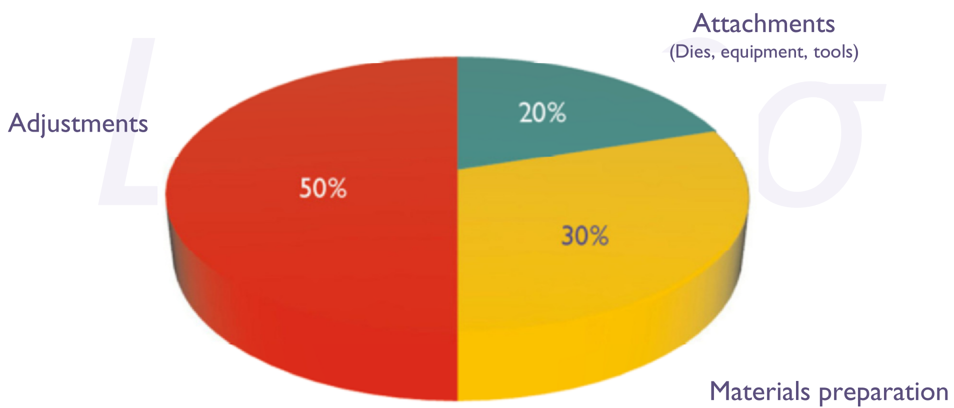
SMED - Single Minute Exchange of Die

Practical tips to improve changeover time performance:

- Use checklist to identify all the material necessary to perform the changeover activities
- Prepare all the raw materials before stopping the machine
- Check the raw materials to avoid placing the wrong one
- Try to plan the set-up in order to reduce the activity between the previous batch and the next one
- Try to perform the pre-heating of molds before machine stoppage in order to reduce scraps because of incorrect temperature of the machine
- Use, "visual changeover" where possible
- Try to standardize size of screws and bolts, height of dies, etc. as much as possible
- Use quick lock and quick release systems
- If possible, use "before and after" approach, all material in line approach, kit management approach or product family approach

SMED - Single Minute Exchange of Die

Typical proportions of the activities in a changeover process:



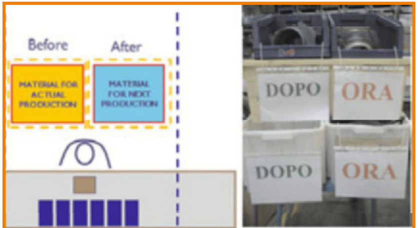
SMED - Single Minute Exchange of Die

Changeover optimization examples:

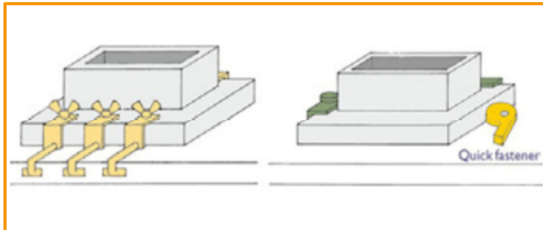



Use Visual Management to identify the right equipment for the changeover

All the tools necessary for the set-up must be prepared before changeover starts



With before and after material management approach the production is already prepared for next batch



Use quick fastener system to reduce the attachment time as much as possible

Kanban

Objective:

- Kanban(G) means 'signboard'. Kanban can be used in many applications in various processes. It is primarily used as an instruction mechanism that controls the production, movement of goods, material, or parts, or jobs. For example, in controlling production, Kanban will tell you what to produce, when to produce, and how much to produce

Benefits of Kanban:

- It is a basic tool for the pull system in production and supply processes
- It effectively reduces the inventory level of work in process (WIP), thus reducing wastes
- It reacts effectively with fluctuating demands from customers or downstream
- It is used to connect two processes with very different lead times
- It is a "visual management" system

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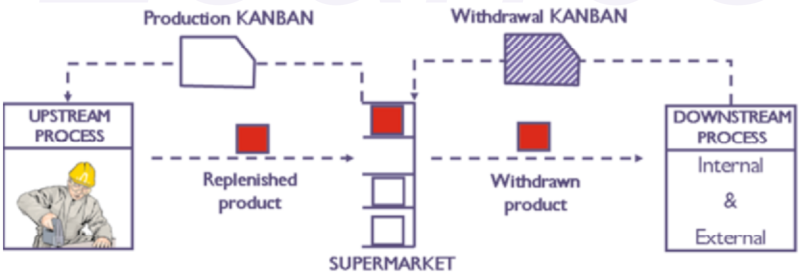
Kanban

Withdrawal Kanban and Production Kanban:

Withdrawal Kanban: is used to order supplies/materials or command movement of process material/parts/semi-finished goods flows

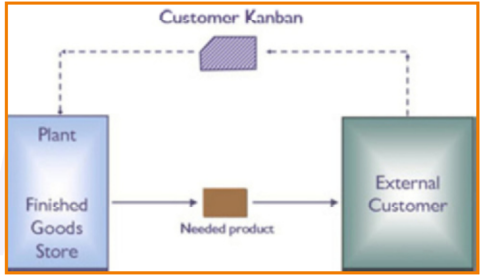
Production Kanban: is used to control production, with detailed command including detailed information relating to quantity, type, destination etc.

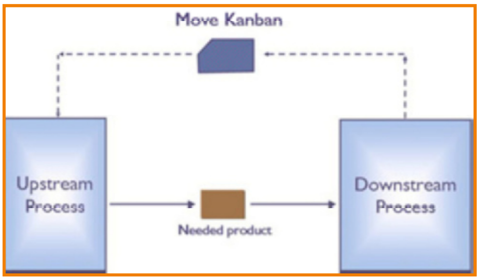


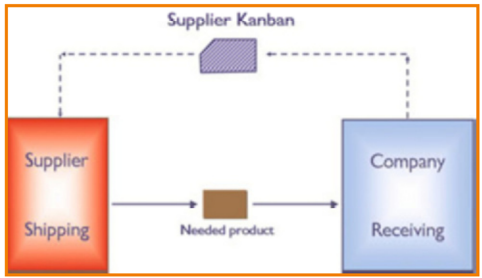
Kanban

Types of Withdrawal Kanbans:

- Customer Kanban
  - Transfers material from plant to customer
- Move Kanban
  - Transfers material between work processes
- Supplier Kanban
  - Pulls material from supplier to plant



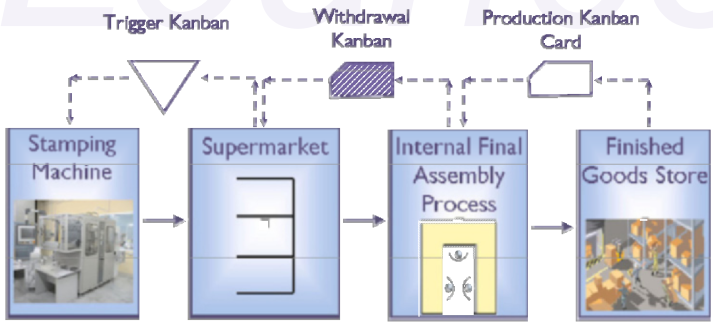




Kanban

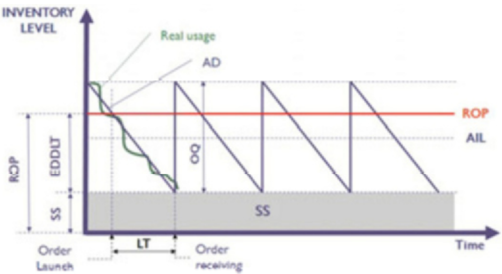
Types of Production Kanban:

- **Production Kanban Card**
  - Gives instructions how to make one piece or one container
- **Trigger Kanban**
  - Instructs us to produce one batch
  - Used when the processes require set-up. The Kanban authorizes production only when the number of units to replenish is equal to the "Economic Order Quantity"



Kanban

Kanban sizing (analytical approach):



- EDDLT = Expected Demand During Lead Time (n° pcs)
- AD = Average Demand per day (n° pcs/day)
- OQ = Order Quantity (n° pcs)
- ROP = Reorder Point (n° pcs)
- AIL = Average Inventory Level (n° pcs)

AIL = OQ / 2 + SS

- LT = Total Lead Time (Production LT + Delivery LT (Days))
- SS = Safety Stock (n° pcs)

SS = n° extra days x AD

- Q= Size of container (n° pcs)

EDDLT = AD x LT
ROP = EDDLT + SS

n° Kanban = ROP / Q

SOME PRACTICAL TIPS:

- The minimun number of kanban is 2
- The Kanban number must be increased to one unit if the process starts with one empty bin
- If the bin is at the point of usage the Kanban number must be increased by one unit

Kanban

How to implement Kanban Process:

- Perform Kanban sizing
- Realize physical Kanban (bins, cards, etc.)
- Organize *supermarket*
- Implement FIFO mechanism
- Use "Visual Management approach" (blackboard, labels, colored bins, etc.)
- Organize point of collection
- Train the people involved in kanban process
- Implement Kanban performance dashboard (Inventory level; Number of stock shortages, etc.)

(Example kanban collection point)

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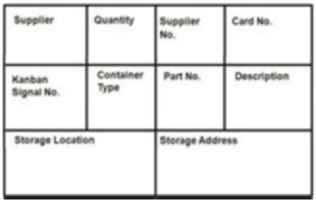
CAUTION:

Don't forget to start from products with high inventory turn index

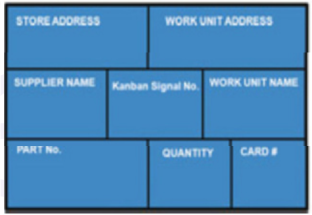
Kanban

Kanban Card Designs:

Customer Kanban

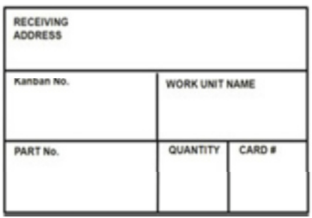


Move Kanban



Supplier Kanban

Production Kanban Card



Trigger Kanban

Heijunka

What is Heijunka?

- Heijunka(G) can be defined as "pursuit of even distribution of production volume and production mix over time"

Why Heijunka is beneficial?

- Customer demands for products are uneven and non smooth in nature. However, the production processes work well at an even and smooth pace, Heijunka can effectively convert uneven demands into even ones and predictable production process by leveling production volume and mix
- Heijunka can be used in combination with other Lean tools, such as Kanban, and SMED to create smooth value flow

Components of Heijunka:

1. Production leveling
2. Product mix leveling
3. Heijunka box

Heijunka

Why Production Volume Leveling?

- Fluctuations in customer demand often create greater disturbances in upper stream processes and supply chains
- Chasing variations in demand with fluctuation in production often causes: alternating overtime and idle time, quality problems, higher costs and stressed out workers

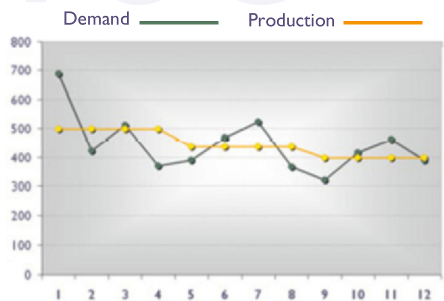
What is Production volume Leveling?

Week	Demand	Weekly leveled production
1	686	497
2	422	497
3	511	497
4	369	497
5	390	437
6	468	437
7	523	437
8	367	437
9	320	397
10	416	397
11	462	397
12	390	397

1988 / 4 = 497

1748 / 4 = 437

1588 / 4 = 397

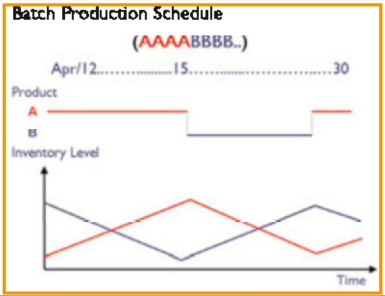


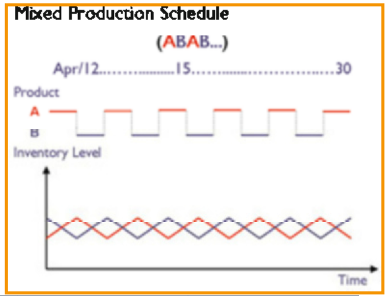
Heijunka

Why Product Mix Leveling?

- Large batches of the same product may reduce number of changeovers, but it usually causes long lead time and high inventory level
- Variations in daily work loads will lead to uneven work pace, possibly creating excessive idle time, overtime, and reducing quality
- A daily production schedule with stable product mix and stable work load will make a stable production process

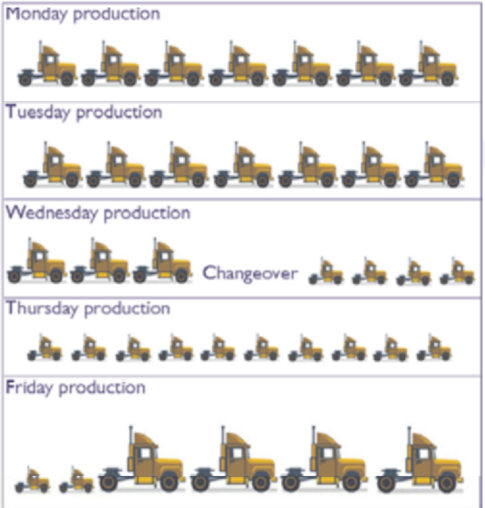
What is Product Mix Leveling?



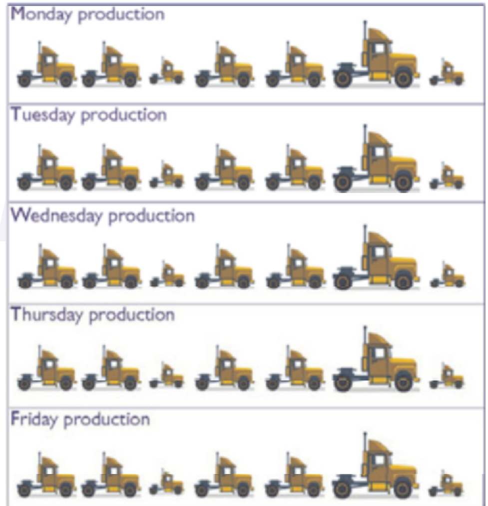


Heijunka

A Product Mix Leveling Example:



Batches, uneven daily loads

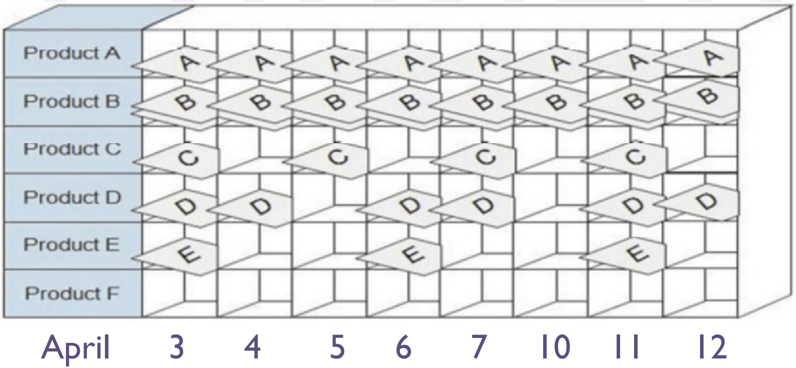


Stable mix, stable daily loads

Heijunka

What is Heijunka box?

- The Heijunka box is a visual scheduling tool for Heijunka application, both production volume leveling and product mix leveling are visually displayed



TPM - Total Productive Maintenance

Objective:

- Total Productive Maintenance (TPM) is a methodology focused on the technical aspects of manufacturing processes. It aims to increase plant and equipment productive performances through employees' empowerment and skills. For that reason the real owner of the methodology is not only maintenance but all the production system

TPM pillars:

- Total Productive Maintenance is based on 8* pillars
  - Focus improvement
  - Autonomous Maintenance
  - Planned Maintenance
  - Quality maintenance
  - Early equipment management
  - Office TPM
  - Education and training
  - Safety, Health and environment

* The number of pillars can change from company to company

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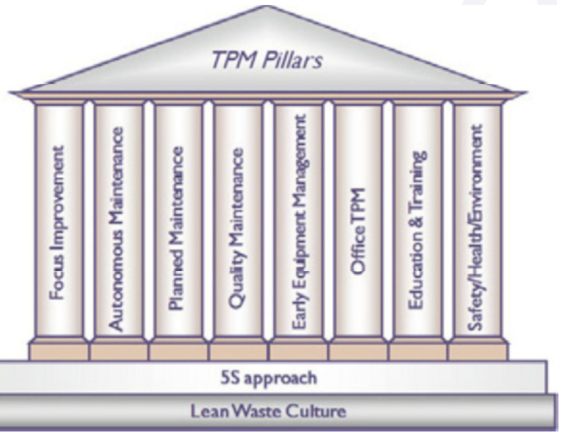
TPM - Total Productive Maintenance

Overview:

- The TPM methodology is represented by a temple where at the base there are two important points: lean waste culture and 5S approach (don't forget to use them everytime you look at the process optimization)



TPM - Total Productive Maintenance -

What is the meaning of the 8 pillars?

FOCUS IMPROVEMENT

Focus Improvement, or Kobetsu Kaizen, aims to maximize the overall system efficiency (generally measured with OEE index) through the elimination of equipment/process losses. It is one of the most important activities because of its rapid implementation and impact dimension. This pillar is strictly related to all other pillars

PLANNED MAINTENANCE

Planned maintenance aims to move away from reactive maintenance to a proactive approach (planned maintenance). The activity is complementary to autonomous maintenance and generally requires the maintenance team. It aims to improve the technique and practice of maintenance, due to the increase of skills and ability to use diagnostic techniques. The ideal goal is "Zero breakdowns"

AUTONOMOUS MAINTENANCE

Autonomous maintenance is the involvement of production workers in machine/equipment management through the transfer of some activity like daily inspection, lubrication, cleaning, minor repairs, etc. typical of a maintenance team. The operator is the expert on the equipment and for this reason he is primarily responsible for machine care. Continuous improvement is the basis of this pillar

QUALITY MAINTENANCE

Quality Maintenance aims to create and maintain the conditions of the process from which the products come in order to ensure the quality level required by the customer. The starting point is not the product but the process control and consequently the management of its conditions (eg. pressure, temperature, density, flow rate, etc.) to maintain the desired result

TPM - Total Productive Maintenance -

What is the meaning of the 8 pillars?

EARLY EQUIPMENT MANAGEMENT

Early Equipment Management is a structured process focusing on reducing the complexity associated with the operation and maintenance of equipment. It helps to extend the principles of Lean to the design and manufacture of equipment

EDUCATION & TRAINING

Education and training pillar is the basis of TPM. Its goal is to ensure that all people involved in TPM have all the skills necessary to support the change. Improving knowledge and skills of operators will not only increase their operational abilities, but encourage pride in their work, with great benefits to all. The two main ways to reach this are "on the job training" and "self-development"

OFFICE TPM

The Office TPM pillar aims to involve the non-productive departments to focus on better plant performance. The pillar helps administrative functions in defining their goals to support the TPM process in the production area

SAFETY, HEALTH, ENVIRONMENT

This pillar is really important for all company systems. TPM doesn't only mean more efficiency of equipment or less defects, but also eliminates all problems related to safety and environment. The main goal is to create a workplace that is organized, safe and environmentally oriented

Priority Matrix

Objective:

- *Priority Matrix* can be used to quantify the degree of correlation between Input and Output variables
- In addition, it is often used to identify the best solutions according to criteria, weighting them appropriately (e.g. it can be useful when consensus is not reached in making a group decision)
- In a Lean Six Sigma project, this method can be used in Measure Phase to identify linkage between input and output variables. It can be used in Improve Phase to identify key variables/solutions to be implemented in order to solve the problem

Priority Matrix

How to Build a Priority Matrix*:

1. Identify criteria for evaluating different solutions
2. Team members assign weight to all criteria. For each member, all weight assigned to criteria should added up to 1 (0 is allowed in weighting)

	Marco	Stefano	Claudio	Mirko	
Criterion 1		0,1	0,2		0,3
Criterion 2	0,25	0,45	0,4	0,6	1,7
Criterion 3		0,2	0,1		0,3
Criterion 4	0,25	0,25	0,2	0,4	1,1
Criterion 5	0,5		0,1		0,6
	1	1	1	1	

* The example is related to a case of selecting the optimal solution in which four people suggest the selection criteria and the weight to be associated with the solutions to implement

Priority Matrix

3. Sum the values for each criteria to get the total weight

	Marco	Stefano	Claudio	Mirko	
Criterion 1		0,1	0,2		0,3
Criterion 2	0,25	0,45	0,4	0,6	1,7
Criterion 3		0,2	0,1		0,3
Criterion 4	0,25	0,25	0,2	0,4	1,1
Criterion 5	0,5		0,1		0,6
	1	1	1	1	

	Evaluation criterion 1	Evaluation criterion 2	Evaluation criterion 3	Evaluation criterion 4	Evaluation criterion 5	
Weights	0,3	1,7	0,3	1,1	0,6	TOTAL
Solution A						
Solution B						
Solution C						
Solution D						

Priority Matrix

4. Each evaluator assigns a score of 1, 3 or 5 to rate the ability of each solution to satisfy a criterion
5. Sum the scores from all evaluators and multiply the result by the weight assigned for each criteria, and fill out the following matrix

	Evaluation criterion 1	Evaluation criterion 2	Evaluation criterion 3	Evaluation criterion 4	Evaluation criterion 5	
Weights	0,3	1,7	0,3	1,1	0,6	TOTAL
Solution A	(5+5+5+3)x0,3	(1+3+3+3)x1,7	(5+3+3+1)x0,3	(5+3+5+3)x1,1	(5+1+1+3)x0,6	
Solution B	(3+3+1+1)x0,3	(1+1+1+3)x1,7	(5+3+1+1)x0,3	(5+5+5+3)x1,1	(5+3+3+1)x0,6	
Solution C	(5+1+1+1)x0,3	(5+5+1+1)x1,7	(5+5+5+1)x0,3	(1+1+1+1)x1,1	(5+3+1+1)x0,6	
Solution D	(5+3+3+1)x0,3	(5+1+1+1)x1,7	(5+3+1+1)x0,3	(5+5+5+3)x1,1	(3+1+1+3)x0,6	

Priority Matrix

6. Sum the values for all rows to get the total score for each solution. The solution with the highest score means that this solution is the best one in terms of ability to fairly satisfy all weighted criteria

	Evaluation criterion 1	Evaluation criterion 2	Evaluation criterion 3	Evaluation criterion 4	Evaluation criterion 5	
Weights	0,3	1,7	0,3	1,1	0,6	TOTAL
Solution A	5,4	17	3,6	17,6	6	49,6 A
Solution B	2,4	10,2	3	19,8	7,2	42,6
Solution C	2,4	20,4	4,8	4,4	6	38
Solution D	3,6	13,6	3	19,8	4,8	44,8

A This is the solution that has the highest impact based on weighted criteria

FMEA

Objective:

- FMEA[G] (*Failure Modes and Effects Analysis*) is used to identify a detailed list of failure modes of a product or process and their corresponding causes and then rate them with severity level, likelihood of occurrence and detection in order to manage system risk
- In Lean Six Sigma projects, FMEA can be used as a systematic method to link inputs with outputs, assign priority levels and degree of relationship, or to assess risk associated with different solutions to be implemented. For these reasons this technique can be applied to different stages of DMAIC

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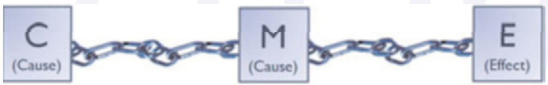
FMEA

RPN (*Risk Priority Number*) is a risk management index that is the product of the following 3 values:

- O: *Occurrence* or probability of occurrence, which relates to causes
- S: *Severity* of the failure effect
- D: *Detection*, Chance of detecting the failure before it happens



Aspect	Index	Range
Failure mode	Detection (D)	1 - 10
Cause	Occurrence (O)	1 - 10
Effect	Severity (S)	1 - 10

$$RPN = O \times S \times D$$

Rule of Thumb:

Corrective action must be taken if RPN value exceeds a threshold (e.g., 100) or severity exceeds 8

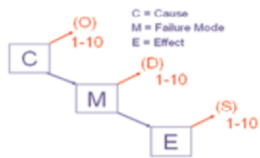
FMEA

1. Identify potential failure modes
2. Identify potential failure effect and its severity (Severity)
3. Identify the failure causes and the likelihood of occurrence (Occurrence)
4. Identify the effectiveness of current system to detect failure (Detection)
5. Multiply the values (S, O, D) to determine the risk level of each failure mode (RPN)
6. Identify the corrective actions for the failure modes that have high RPN value (greater than the threshold value) or when Severity value is more than 8 (9 or 10)
7. Recalculate RPN after improvement. Check the improvement until both RPN and Severity values are acceptable

FMEA

Feature	O Value	Likelihood of Occurrence	Feature	S Value
Very low likelihood	1	<1/100.000	Slight	1 2
Low likelihood	2 3	<1/20.000 <1/10.000	Slightly important	3 4
Medium likelihood	4 5 6	<1/2.000 <1/1.000 <1/200	Moderate	5 6
High likelihood	7 8	<1/100 <1/20	High	7 8
Very hight likelihood	9 10	<1/10 >1/10	High (Safety problems)	9 10

Feature	D Value	Likelihood of Detection
Very high	1 2	=100% > 99%
High	3 4	>95% >90%
Medium	5 6	>50% >20%
Low	7 8	>10% >5%
Very low	9 10	>1% =0%



RPN = O x S x D

FMEA

Example of FMEA application:

PART / PROCESS STEP	MODE	EFFECT	CAUSE	PARAMETERS			RPN (Risk Priority Number)	CORRECTIVE ACTIONS	Responsability	PARAMETERS After corrective actions			RPN (Risk Priority Number)
				O	D	S				O	D	S	
Step 1	Mode 1.1	Effect 1.1	Cause 1.1	3	5	6	90						0
			Cause 1.2	2	5	6	60						0
	Mode 1.2		Cause 1.3	8	3	6	144	Action 1.3	P.White	3	3	8	72
			Cause 1.4	5	3	6	90						0
Step2	Mode 2.1	Effect 2.1	Cause 2.1	6	8	3	144	Action 2.1	G. Blue	6	5	3	90
			Cause 2.2	5	8	3	120	Action 2.2	G. Blue	5	5	3	75
	Mode 2.2	Effect 2.2	Cause 2.3	3	9	4	108	Action 2.3	G. Blue	3	2	4	24
Step 3	Mode 3.1	Effect 3.1	Cause 3.1	2	2	10	40	Action 3.1	V. Black	7	3	4	84
	Mode 3.2	Effect 3.2	Cause 3.3	3	2	7	42						0
	Mode 3.3			3	1	7	21						0
			Total risk index =				859	Total risk index (After) =					345

DOE

Objective:

- DOE[G] (*Design Of Experiments*) is a methodology that builds, through well-planned experiments and analysis of the experimental results, the analytical model relating to the cause-effect relationship between input and output variables

Fundamental Assumptions:

- Residuals (difference between actual response and model prediction) is normally distributed
- Residuals are independent of Xs (Input variables)
- Residuals are independent of predicted Ys (Fitted Value)
- Residuals are independent of time

When to use it:

- DOE can be used in Analyze Phase to identify key variables and interactions that influence the output. DOE can also be used in the Improve Phase to identify best parameter settings (Inputs) to optimize the Output variable

DOE

1. Define the problem
2. Select output (response) variable y
3. Select experimental factors (input variables), their levels and values
4. Select the experimental design in order to manage the number of tests. You can choose *Full Factorial Design*, which is a complete combination of all the levels of all factors, or *Fractional Factorial Design*, which is a selected portion of full factorial design. Fractional Factorial is economical but it lacks some information (some data analysis issues can be handled via *alias structure*, *resolution* and *confounding*)
5. Conduct experiments properly (randomization may be needed, proper data collection, etc.)
6. Analyze the experimental data

DOE

Types of factorial experiments:

General Full Factorial Design → Run = a x b x c x d x … x n

- a: Number of levels for factor A
- b: Number of levels for Factor B
- n: Replicates

2 Level Full Factorial Design → Run = $n \times 2^k$

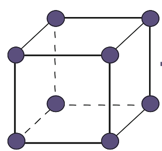
- n: Replicates
- 2: Number of levels
- k: Number of factors

2 Level Fractional Factorial Design → Run = $n \times 2^{k-q}$

- q: Degree of fraction:
  - q = 1 → half fraction 50%
  - q = 2 → ¼ fraction 25%
  - q = 3 → 1/8 fraction 12,5%

Es.

Full Factorial Design for 3 factors

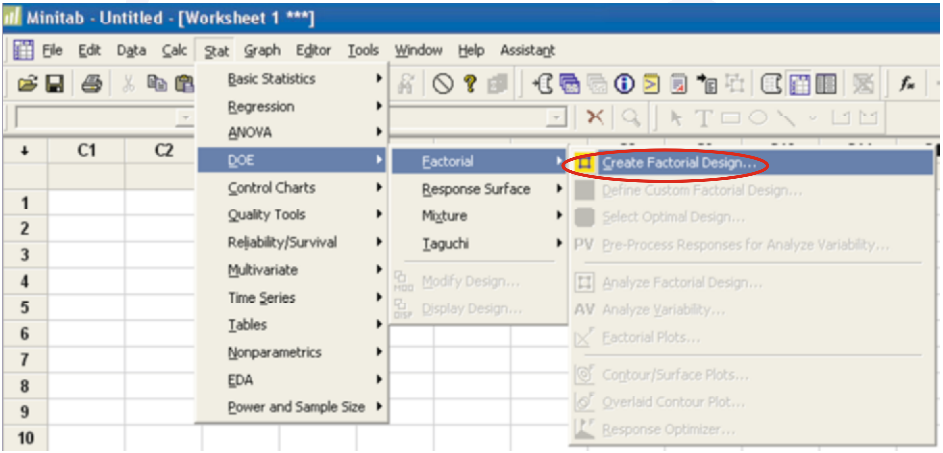


A	B	C
-1	-1	-1
+1	-1	-1
-1	+1	-1
+1	+1	-1
-1	-1	+1
+1	-1	+1
-1	+1	+1
+1	+1	+1

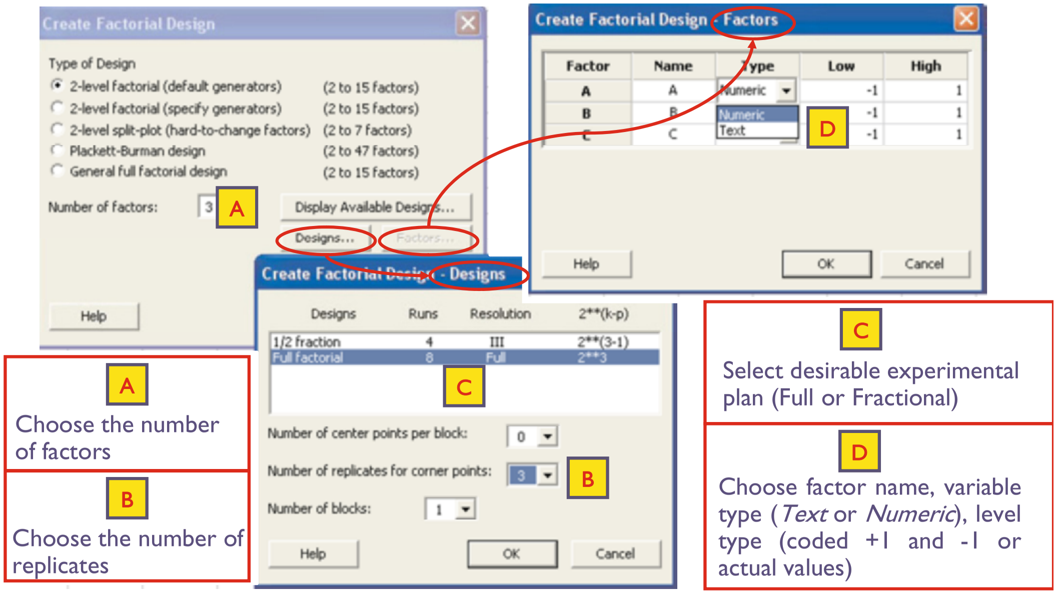
DOE

Create an experimental plan by MINITAB:

Stat > DOE > Factorial > Create Factorial Design…



DOE



Create Factorial Design
Type of Design
2-level factorial (default generators) (2 to 15 factors)
2-level factorial (specify generators) (2 to 15 factors)
2-level split-plot (hard-to-change factors) (2 to 7 factors)
Plackett-Burman design (2 to 47 factors)
General full factorial design (2 to 15 factors)
Number of factors: 3
Display Available Designs...
Designs...
Factors...
Help
Create Factorial Design - Designs
Designs Runs Resolution 2**(k-p)
1/2 fraction 4 III 2**(3-1)
Full factorial 8 Full 2**3
Number of center points per block: 0
Number of replicates for corner points: 3
Number of blocks: 1
Help
OK
Cancel
Create Factorial Design - Factors
Factor Name Type Low High
A A Numeric -1 1
B B -1 1
C C -1 1
Numeric
Text
Help
OK
Cancel
A
Choose the number of factors
B
Choose the number of replicates
C
Select desirable experimental plan (Full or Fractional)
D
Choose factor name, variable type (Text or Numeric), level type (coded +1 and -1 or actual values)

DOE

MINITAB: Output

↓	C1 StdOrder	C2 RunOrder	C3 CenterPt	C4 Blocks	C5 A	C6 B	C7 C
1	2	1	1	1	1	-1	-1
2	10	2	1	1	1	-1	-1
3	13	3	1	1	-1	-1	1
4	20	4	1	1	1	1	-1
5	21	5	1	1	-1	-1	1
6	23	6	1	1	-1	1	1
7	6	7	1	1	1	-1	1
8	11	8	1	1	-1	1	-1
9	22	9	1	1	1	-1	1
10	5	10	1	1	-1	-1	1
11	15	11	1	1	-1	1	1
12	24	12	1	1	1	1	1
13	8	13	1	1	1	1	1
14	12	14	1	1	1	1	-1
15	14	15	1	1	1	-1	1
16	4	16	1	1	1	1	-1
17	16	17	1	1	1	1	1
18	3	18	1	1	-1	1	-1
19	7	19	1	1	-1	1	1
20	17	20	1	1	-1	-1	-1
21	19	21	1	1	-1	1	-1
22	18	22	1	1	1	-1	-1
23	1	23	1	1	-1	-1	-1
24	9	24	1	1	-1	-1	-1

A

Full Factorial Design

B

```
Factors:    3   Base Design:          3; 8
Runs:      24   Replicates:              3
Blocks:     1   Center pts (total):      0

All terms are free from aliasing.
```

A

Experimental plan created

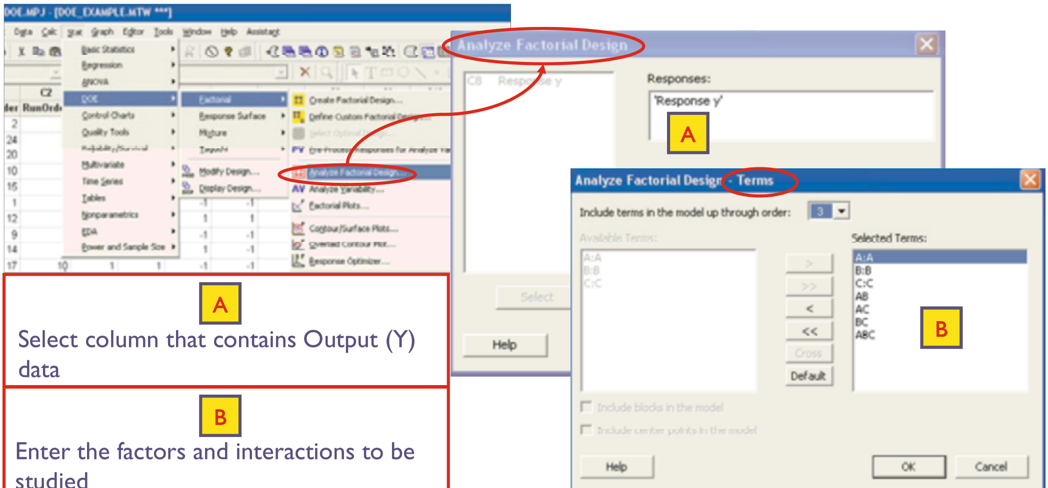
B

Experimental design information displayed in *session window*

DOE

Manage statistical analysis plan

Stat > DOE > Factorial > Analyze Factorial Design…



A

Select column that contains Output (Y) data

B

Enter the factors and interactions to be studied

DOE

MINITAB: Output

Factorial Fit: Response y versus A; B; C

Estimated Effects and Coefficients for Response y (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		0,3223	0,02912	11,07	0,000
A	-0,2143	-0,1071	0,02912	-3,68	0,002
B	-0,0107	-0,0054	0,02912	-0,18	0,856
C	0,2232	0,1116	[illegible]	3,83	0,001
A*B	-0,0268	-0,0134	[illegible]	-0,46	0,652
A*C	-0,2286	-0,1143	2912	-3,92	0,001
B*C	-0,0786	-0,0393	0,02912	-1,35	0,196
A*B*C	0,0125	0,0062	0,02912	0,21	0,833

S = 0,142878 PRESS = 0,732037
R-Sq = 74,08% R-Sq(pred) = 41,60% R-Sq(adj) = 62,74%

Analysis of Variance for Response y (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0,57515	0,575147	0,191716	9,42	0,001
A	1	0,27551	0,275510	0,275510	13,53	0,002
B	1	0,00069	0,000689	0,000689	0,03	0,856
C	1	0,29895	0,298948	0,298948	14,69	0,001
2-Way Interactions	3	0,35482	0,354815	0,118272	5,81	0,007
A*B	1	0,00430	0,004305	0,004305	0,21	0,652
A*C	1	0,31347	0,313469	0,313469	15,40	0,001
B*C	1	0,03704	0,037041	0,037041	1,82	0,196
3-Way Interactions	1	0,00094	0,000937	0,000937	0,05	0,833
A*B*C	1	0,00094	0,000937	0,000937	0,05	0,833
Residual Error	16	0,32571	0,325714	0,020357		
Pure Error	16	0,32571	0,325714	0,020357		
Total	23	1,25661				

CAUTION:

Eliminate factors (one at a time) until all remaining ones are significant

A

For any main effect, two way, three way or higher order interaction, it is significant only if its P-Value < 0.05

B

Regression coefficients for the analytical model

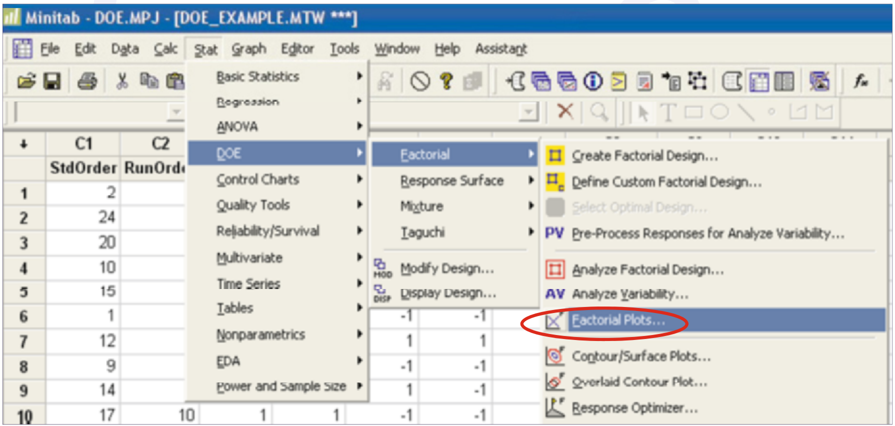
C

Global importance of factors: if its P-Value is < 0.05 , then at least one single factor or interaction (2 way or 3 way, etc.) is significant

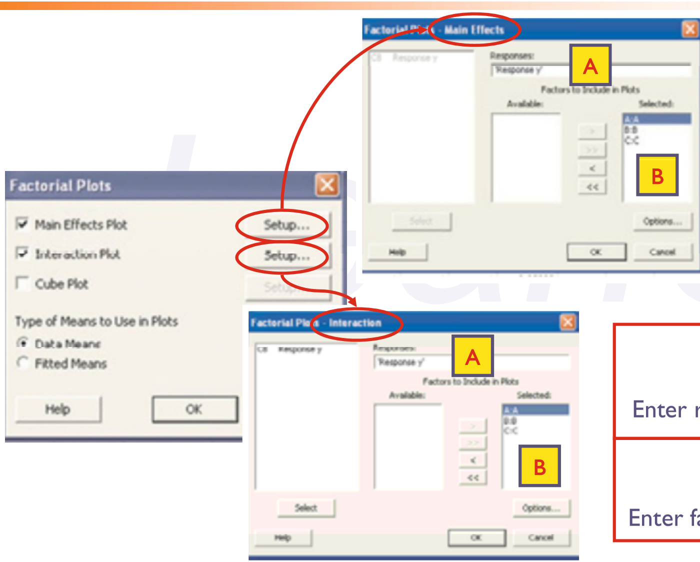
DOE

DOE Graphs

Stat > DOE > Factorial > Factorial Plots…



DOE



A
Enter response variable
B
Enter factors to be analyzed

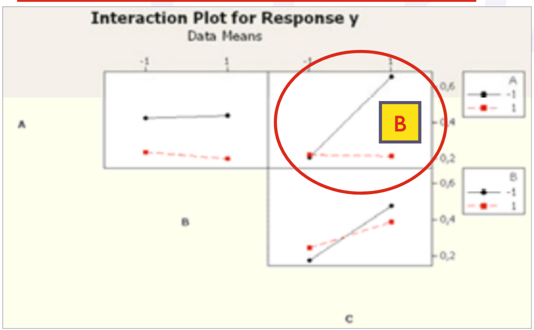
DOE

MINITAB: Output

A

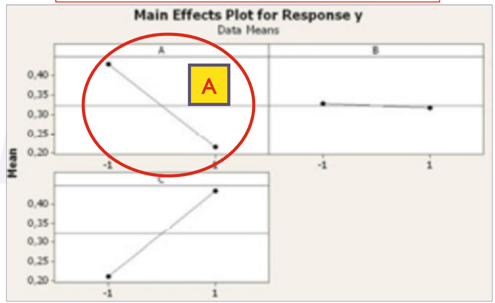
Main Effects Plot

The greater magnitude in slope indicates larger main effect



CAUTION:

Graphical results must be supported by statistical analysis



B

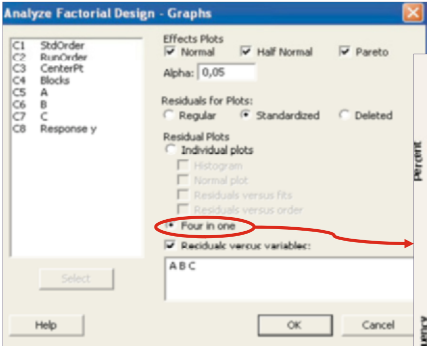
Interaction Plot

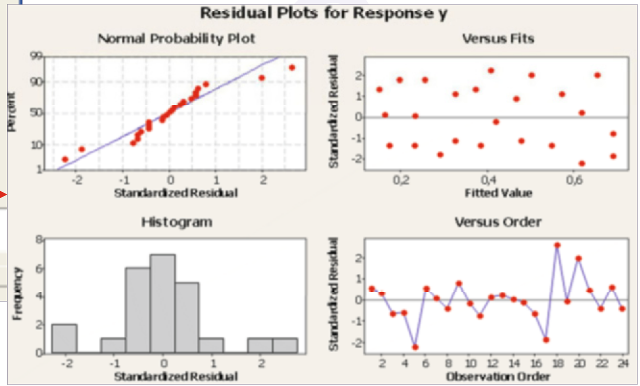
Parallel lines indicate that there is no significant interaction effect

DOE: Assumptions

Residual analysis

Stat > DOE > Analyze Factorial Design…(Graphs)





Residuals must be independent of Xs

Residuals must be independent of time

Residuals must be independent of predicted Ys (Fitted Value)

Residuals should be normally distributed

CONTROL

Arcidiacono G., Calabrese C., Yang K.: Leading processes to lead companies: Lean Six Sigma.
DOI 10-1007/978-88-470-2492-2, © Springer-Verlag Italia 2012

CONTROL

Control is the final step of Lean Six Sigma roadmap; the objective of this phase is to:

- Test the quality level because it is the result of previous Lean Six Sigma steps
- Validate the method and its effectiveness used in improvement
- Standardize the method if its effectiveness is proven
- Implement control plan to sustain the improved long term performance
- Use *visual management* and an *error proofing system* to maintain high level performance
- Verify the applicabilities and possible extensions of the method for other possible problems or company areas

Control Chart

Objective:

- Control Charts are useful tools that can verify and monitor the stability of performance levels for manufacturing, transactional and service processes
- Control Charts are tools that can be used to identify "special causes' in the process

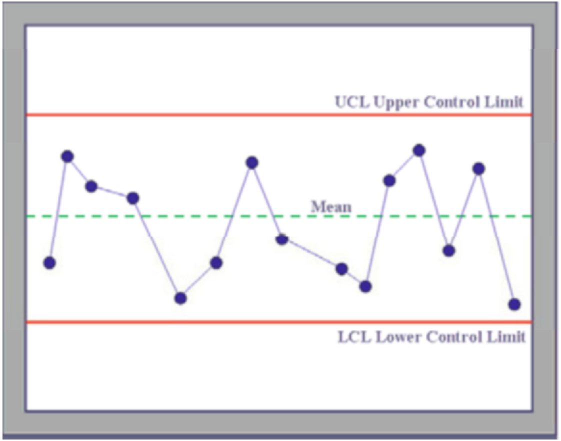
Features:

- **Common Cause**: The cause, random in nature and not related to any special event, is behind natural inherent variability shown in processes
- **Special Cause:** The cause is often associated with special events. The result of a Special Cause is that the process often shows a trend, seasonality or other non-random patterns

A process is "stable" if it is only influenced by random causes (common causes)

Lean6σ

Control Chart: Individuals



When to use it:

- When it is necessary to monitor individual continuous variables

$$UCL = \mu + L\sigma$$
$$CL = \mu$$
$$LCL = \mu - L\sigma$$

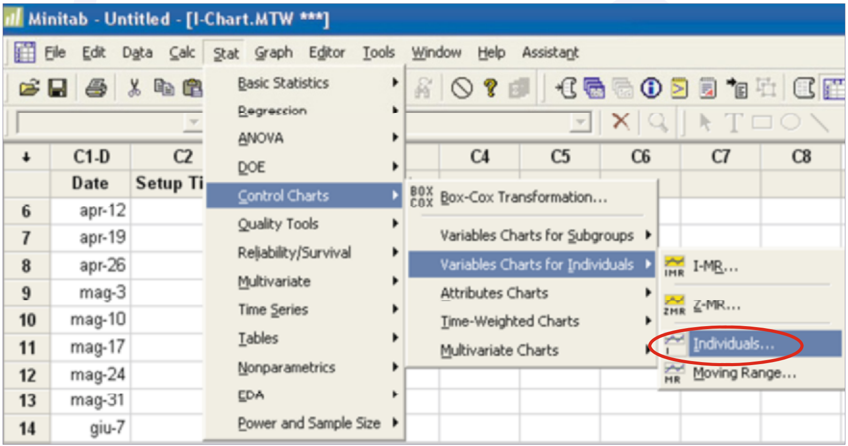
Formula for **control limits** calculation

- Control limits are specified by the **Upper Control Limit** (UCL) and **Lower Control Limit** (LCL), They determine the range for natural variation due to random causes. Any variation beyond UCL or LCL will be considered as 'out of control' and likely caused by a special event

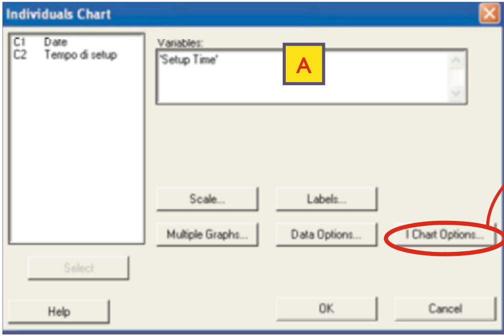
Control Chart: Individuals

MINITAB:

Stat > Control Charts > Variables Charts for Individuals…

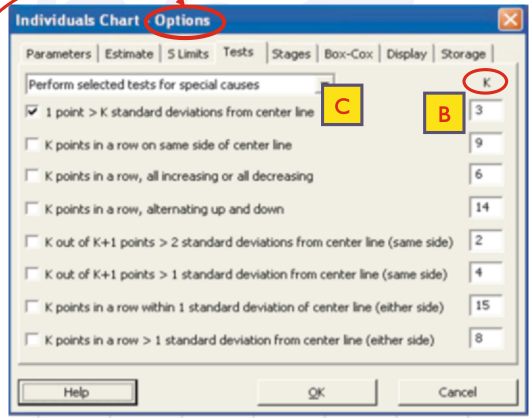


Control Chart: Individuals



A Enter the column that contains Output (Y)

B It is possible to customize the value of K to determine the type of test desired

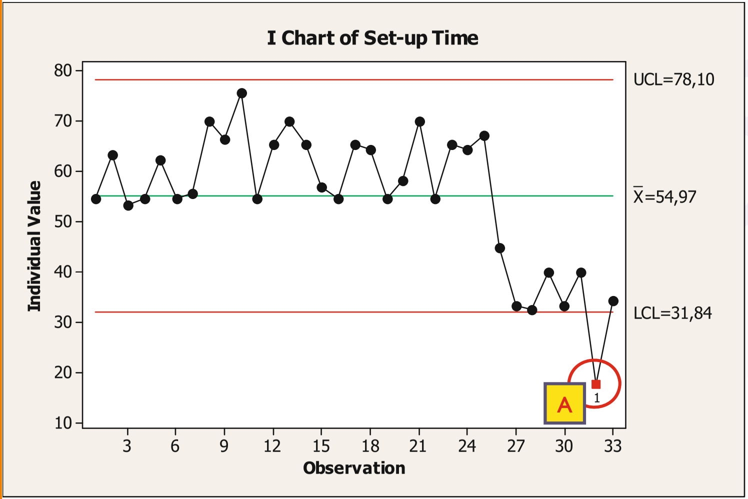


C

Use this option to select desirable tests in order to identify potential non random patterns

Control Chart: Individuals

MINITAB: Output



A

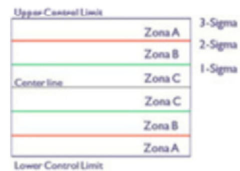
A point outside control limit indicating the presence of special cause

It is necessary to investigate the causes that lead this out of control situation, in order to intervene and correct the problem

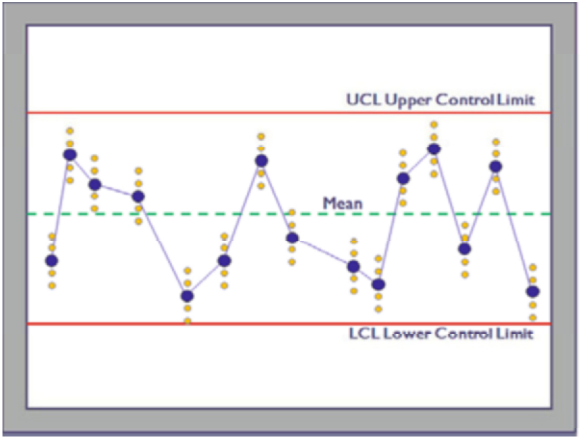
Control Chart: Individuals

Rules to determine out of control and non random trends

- One or more points out of control limits (usually 3-sigma lines)
- Two out of three points are beyond 2-sigma line (warning line) but usually within 3-sigma line
- Four out of five points fall beyond1-sigma line from center
- Eight consecutive points fall on one side of centerline
- Six consecutive points are in ascending or descending order
- 15 consecutive points are in zone C (both above or below centerline)
- 14 consecutive points are alternating up and down (zig-zag)
- 8 consecutive points alternate around centerline, but none in zone C
- Non random patterns are observed



Control Chart: Xbar-R



When to use it:

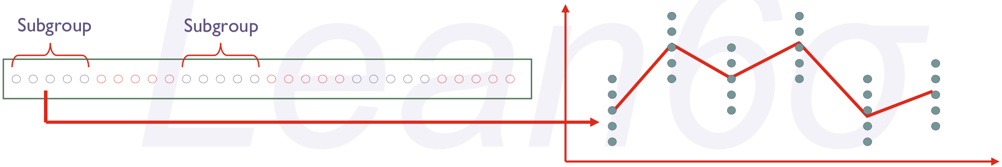
- It is necessary to monitor subgroups of continuous variables
- Xbar-R charts are often used in high volume production process monitoring

- Control limits are specified by the **Upper Control Limit** (UCL) and **Lower Control Limit** (LCL). They determine the range for natural variation due to random causes. Any variation beyond UCL or LCL will be considered as 'out of control' and likely caused by special events

Control Chart: Xbar-R

Rational subgroups are samples that can be used to assess:

- Within group variation
- Between groups variation



Control limits calculation:

Xbar Chart

$$UCL = \bar{\bar{x}} + A_2 \bar{R}$$

$$CL = \bar{\bar{x}}$$

$$LCL = \bar{\bar{x}} - A_2 \bar{R}$$

R Chart

$$UCL = D_4 \bar{R}$$

$$CL = \bar{R}$$

$$LCL = D_3 \bar{R}$$

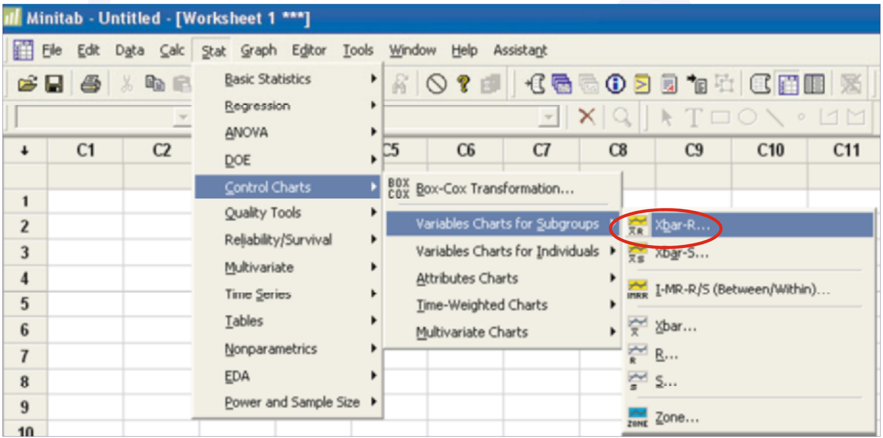
where ⇨

Sample size	Xbar - R Chart		
	A_2	D_3	D_4
2	1,881	0	3,269
3	1,023	0	2,574
4	0,729	0	2,282
5	0,577	0	2,114
6	0,483	0	2,004
7	0,419	0,076	1,924
8	0,373	0,136	1,864
9	0,337	0,184	1,816
10	0,308	0,223	1,777

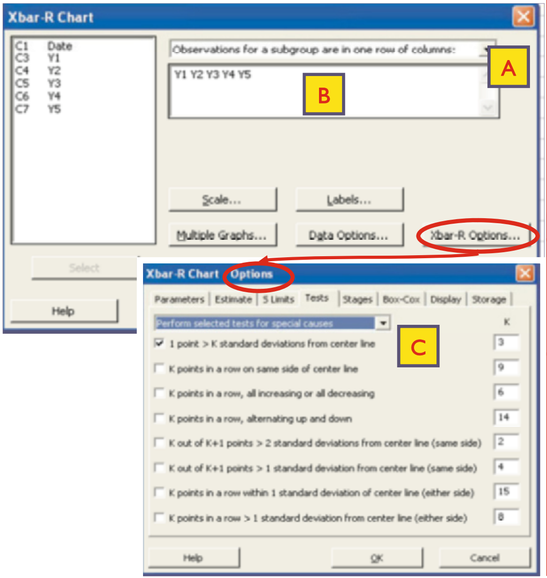
Control Chart: Xbar-R

MINITAB:

Stat > Control Charts > Variables Chart for Subgroups > Xbar-R…

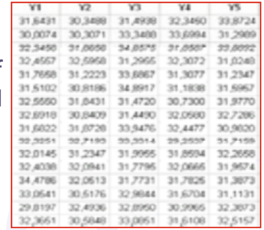


Control Chart: Xbar-R



A

Select this option if the data are arranged in different columns



Y1	Y2	Y3	Y4	Y5
31,6431	30,3488	31,4938	32,3460	33,8724
30,0074	30,3071	33,3480	33,6994	31,2909
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32,4557	32,5958	31,2955	32,3072	31,0248
31,7658	31,2223	33,6867	31,3077	31,2347
31,5102	30,8186	34,8917	31,1838	31,5967
32,5550	31,8431	31,4720	30,7300	31,9770
32,6918	30,8409	31,4490	32,0580	32,7286
31,6022	31,8728	33,9476	32,4477	30,9820
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32,0145	31,2347	31,9955	31,8594	32,2658
32,4038	32,0941	31,7795	32,0665	31,9574
34,4786	32,0613	31,7731	31,7825	31,3873
33,0541	30,5176	32,9844	31,6704	31,1131
29,8197	32,4936	32,8950	30,9965	32,3873
32,3651	30,5848	33,0851	31,6108	32,5157

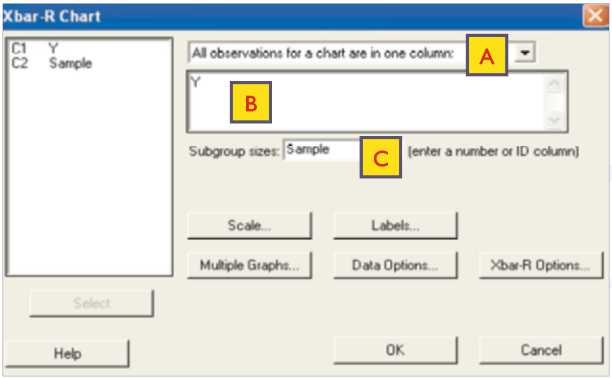
B

Enter the columns that contain Y responses (sample element results)

C

With this command, choose all tests for identifying out of control and non-random patterns, or select only the tests that you want to use

Control Chart: Xbar-R



A

Select this option if all observations are in one column

Y	Sample
31,6431	Sample 1
30,0074	Sample 2
32,3456	Sample 3
32,4557	Sample 4
31,7658	Sample 5
31,5102	Sample 6
32,5550	Sample 7
32,6918	Sample 8
31,6822	Sample 9

B

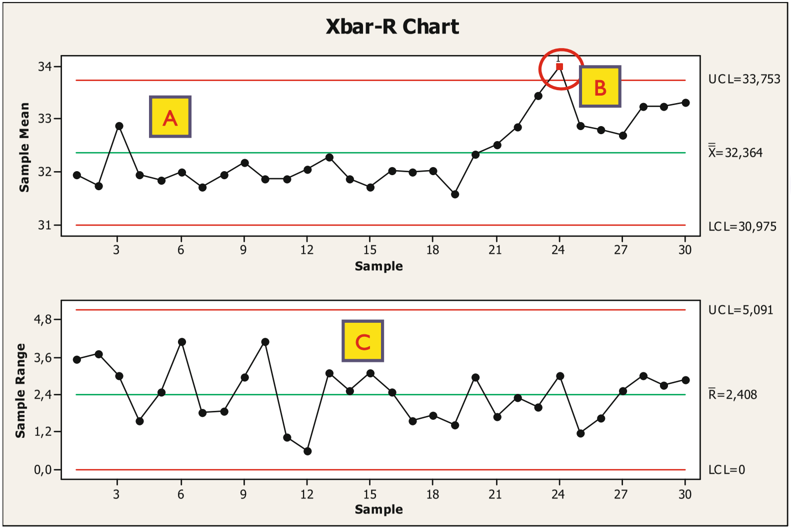
Enter the column that contains response Y to be analyzed

C

Enter the column that contains subgroup labels

Control Chart: Xbar-R

MINITAB: Output

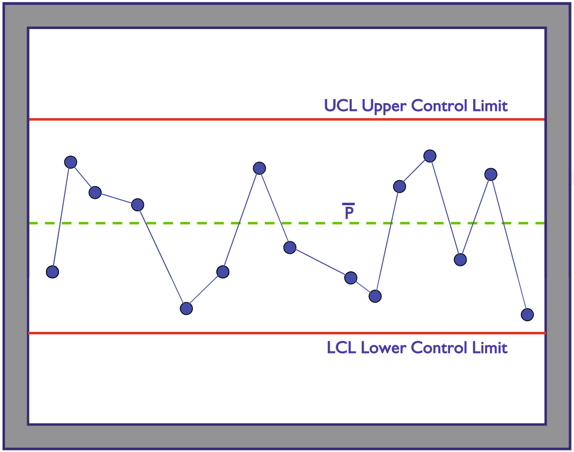


A Xbar Chart: Each point in the chart represents a mean of a sample

B Presence of a special cause

C R Chart: Each point represents the range value in a sample

Control Chart: P Chart



When to use it:

- To monitor the state of inspection units, with 2 states, pass/failure, good/bad, etc. $\bar{p}$ is often the ratio of failure (discrete attribute variables)

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

$$CL = \bar{p}$$

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

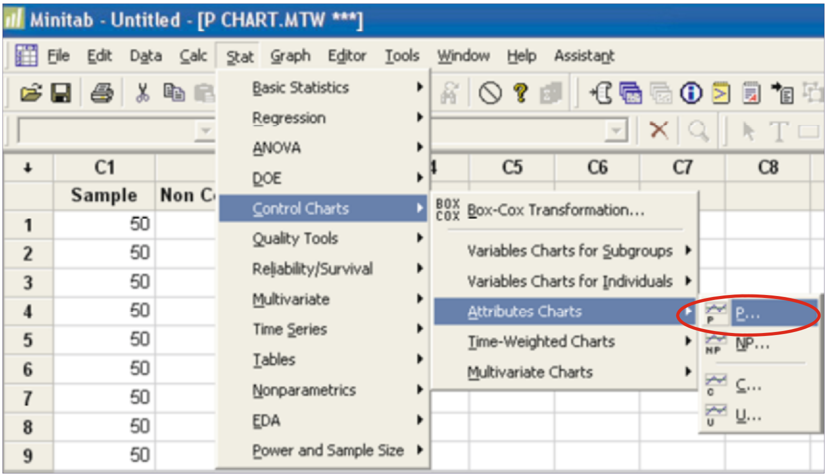
Formula to calculate control limits

- Control limits are specified by the **Upper Control Limit** (UCL) and **Lower Control Limit** (LCL). They determine the range for natural variation due to random causes. Any variation beyond UCL or LCL will be considered as 'out of control' and likely caused by special events

Control Chart: P Chart

MINITAB:

Stat > Control Charts > Attributes Chart > P…



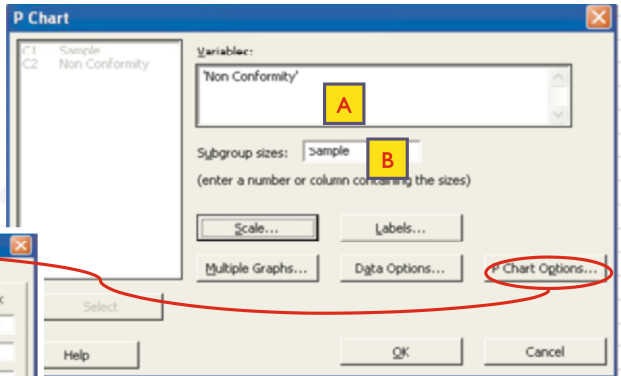
Control Chart: P Chart

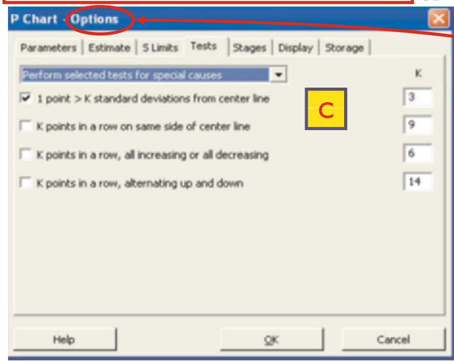
A

Enter the column that contains number of non conformity

B

Enter the column that contains sample sizes



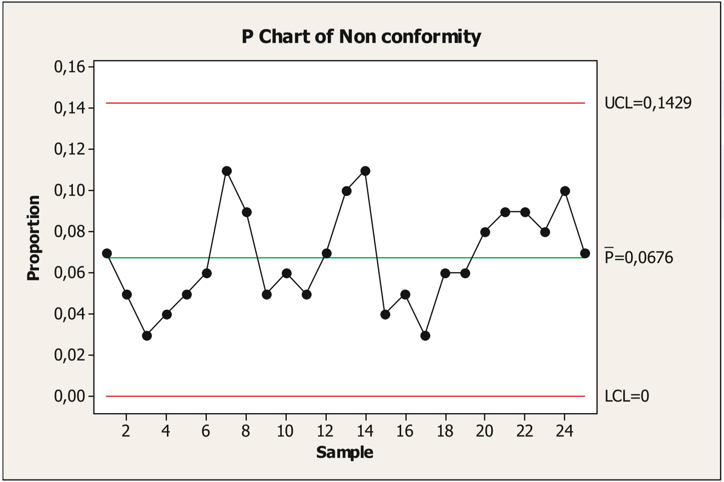


C

Select 'out of control and non random patterns test'. It is possible to make your own choice

Control Chart: P Chart

MINITAB: Output

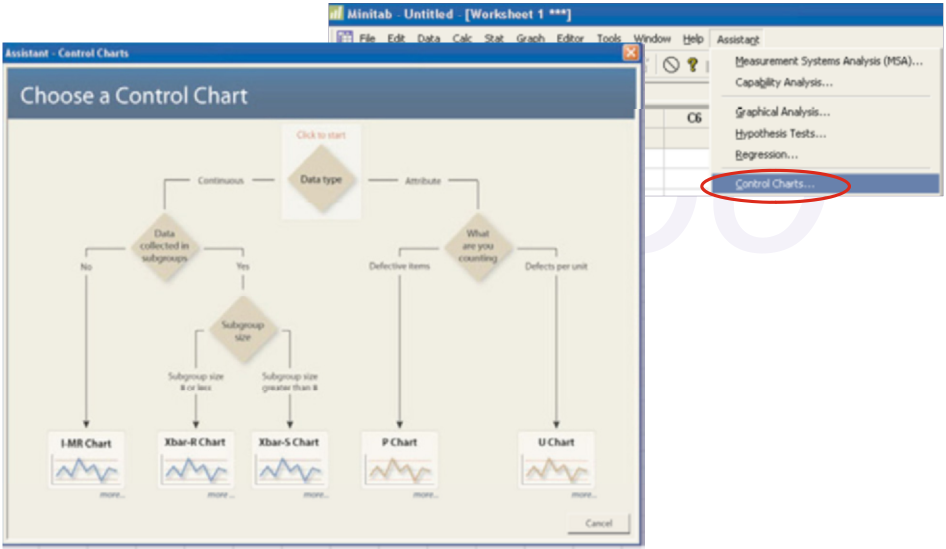


Sample	Non conformity
100	7
100	5
100	3
100	4
100	5
100	6
100	11
100	9
100	5
100	6
100	5
100	7
100	10
100	11
100	4
100	5
100	3
100	6
100	6
100	8
100	9
100	9
100	8
100	10
100	7

In this example, the process appears in the state of statistical control

Control Chart & Minitab

Minitab Assistant helps you to choose the right Control Chart:



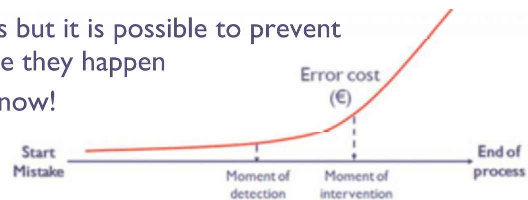
Poka Yoke

Objective:

- Poka Yoke [G] (or *Mistake Proofing*) is one of the techniques that aims to reach the "Zero Defect Quality" through the usage of devices or procedures which allows detection of an error that could lead to waste (scraps, reworks, breakdowns etc.). Poka Yoke could be a design choice (Poka Yoke design) or a detection system on the process (Poka Yoke Process)

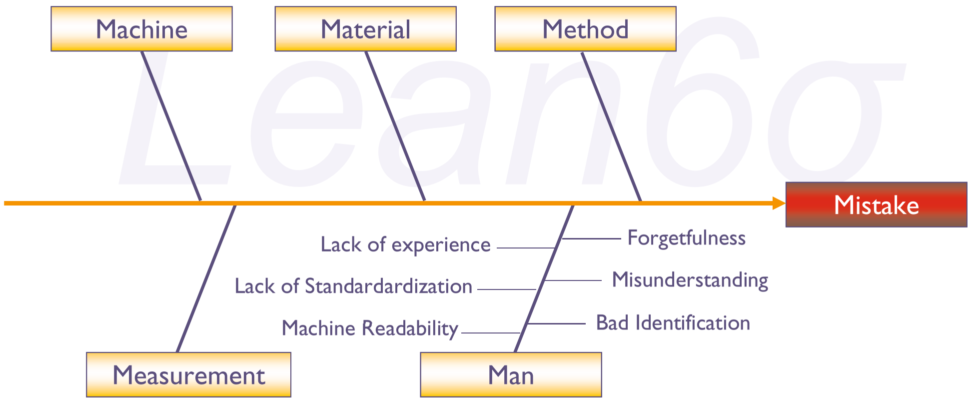
Poka Yoke basic concept:

- An error increases its economic impact if the time between when it happens and its discovery increases
- It is natural that people make mistakes but it is possible to prevent human errors becoming defects before they happen
- Don't try to do better next time: act now!



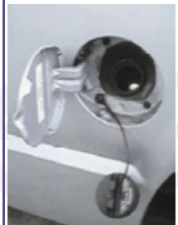
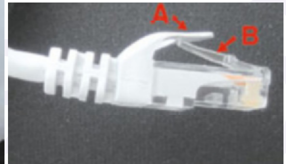
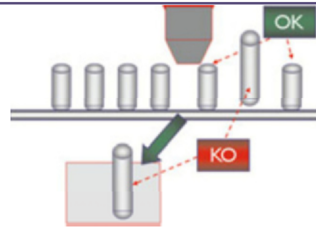
Poka Yoke

Why a mistake could happen:



Poka Yoke

Poka yoke strategy and examples:

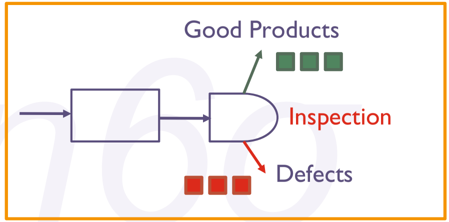
MISTAKE			
	Could happen…	Prevention area	  
	Already happened…	Detection area	 

Poka Yoke

Types of Quality Inspections (Shingo):

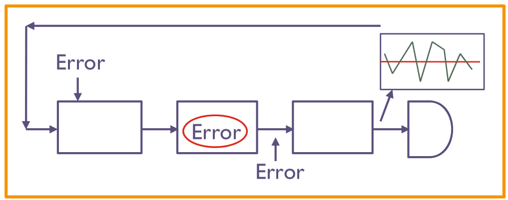
1. **Judgment Inspection:**
   Discover defects after the facts, sort out bad products

   Disadvantages:
   - costly
   - difficult to eliminate all defects if human inspection is used
   - no feedback to process



2. **Statistical Process Control (SPC):**
   A sampling based inspection and process feedback

   Disadvantages of SPC (Shingo):
   - it is a sample inspection, so if the process is not capable, it cannot catch all the defects
   - the feedback is usually slow

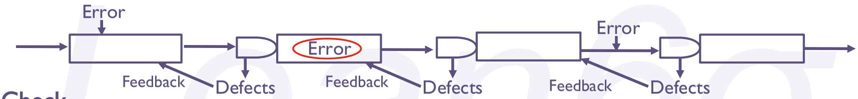


Poka Yoke

Desirable Types of Quality Inspections (Shingo):

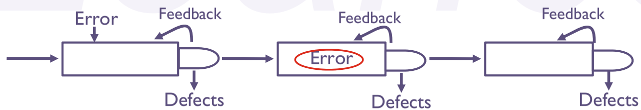
1. Successive Check

Successive check is to let the immediate downstream process check output of the immediate upstream process



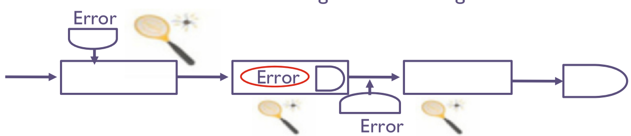
2. Self Check

Self check is to let current process check itself and trouble shoot the process immediately if defect occurs



3. Source Inspection

Source inspection is based on the idea of discovering and correcting errors before errors become a defect



Poka Yoke

Basic Principles of Good Quality Inspections (Shingo):

1. Always 100% Inspection
2. Judgment about defects should be done objectively
3. Inspection should be done automatically at low cost
4. When a defect occurs, information should be immediately given as feedback and root causes immediately investigated
5. Discover hidden root causes one at a time, and eliminate them one by one
6. It is desirable to track the source of root cause therefore automatic inspection devices should be installed (Source Inspection)

Poka Yoke System for Perfect Quality Inspection:

1. Poka Yoke device should be cheap, able to perform 100% inspection, and gives results instantly
2. Poka Yoke system can detect abnormalities by detection technology and/or process procedures

Poka Yoke

3 Types of Regulatory Mechanisms for Poka Yoke:

1. **Control:**
   When abnormalities occur, the Poka Yoke system will halt the operations

Example: Coffee Pot

Type of Inspection:
Source Inspection

Poka Yoke Detection Mechanism:
Cheap Device

This automatic coffee pot is equipped with a "pause and serve" feature. The lid of the pot presses up the button (shown above right), releasing a valve which allows the coffee to pour into the pot. If you remove the pot before brewing is finished, the valve closes, so coffee is not spilled

Poka Yoke

3 Types of Regulatory Mechanisms for Poka Yoke:

2. Warning:

When abnormalities occur, the Poka Yoke system will send warning

Example 1: Bathroom Poka Yoke

Some people may hang coat in a bathroom stall and then walk out without it. A stall door in a bathroom is designed so you cannot unlatch the door without dropping your coat unless you remove the coat first

Type of Inspection: Source Inspection
Poka Yoke Detection Mechanism: Smart layout design

Example 2: Warning Color

In a hospital, the circular ring changes from purple to pink when water exceeds 40 degrees Celsius to avoid hurting patients

3 Types of Regulatory Mechanisms for Poka Yoke:

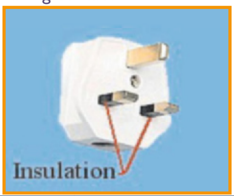
3. Mistake proof:

When abnormalities occur, the Poka Yoke system will make mistakes impossible to happen

Example 1: Electrical Plug

British 240v/50Hz electricity can injure people so electrical plugs are designed so that live electrical pins are never exposed:

1. the position and orientation of the pin are such that the plug can only fit one way in the socket
2. the pins are insulated near the plug body so that an electric shock is not possible via the exposed pin if the plug is not pushed all the way in but still making contact

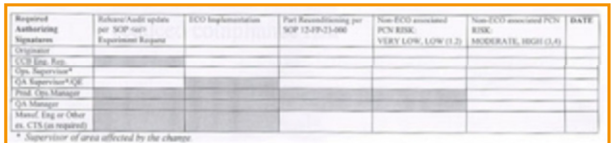


Example 2: Signatures Sheet

AUTHORIZING SIGNATURES

Operations Engineering Manager: ____ Date : ____
EM/EQA Supervisor: ____ Date : ____
Manufacturing Engineer: ____ Date : ____
Other (As Required): ____ Date : ____
Operations Manager: (MED. or HIGH RISK ONLY) ____ Date : ____
EQA Manager: (MED. or HIGH RISK ONLY) ____ Date : ____

Engineering change form requires different signatures depending on the nature of the change being considered. Sometimes engineers would get too many signatures, and sometimes not enough



Required Authorizing Signatures	Rehearse/Audit update per SOP (or) Experiment Request	ECO Implementation	Part Reconditioning per SOP 12-FP-23-000	Non-ECO associated PCN RISK: VERY LOW, LOW (1,2)	Non-ECO associated PCN RISK: MODERATE, HIGH (3,4)	DATE
Originator						
CCB Eng. Rep.						
Ops. Supervisor*						
QA Supervisor*/QE						
Prod. Ops Manager						
QA Manager						
Manuf. Eng or Other ex. CTS (as required)						

* Supervisor of area affected by the change

The revised form identifies the nature of the change in the columns and indicates unnecessary signatures in gray. Creating forms that help the user fill them out correctly is a part of mistake-proofing

Visual Management

Objective:

- Visual Management[G] is a method that makes all processes in a company visual and tangible. Applying visual management will make the workplace well structured and processes will be clear to everybody at all levels (from top management to shopfloor). In other words "Make it visual"

Why to use it:

- Visual Management has many advantages:
  - The detection of normal and abnormal operating conditions is easy and rapid
  - Time reduction
  - Space reduction
  - Costs reduction
  - … in general *waste reduction*

Lean6σ

Visual Management

How to implement Visual Management:

1. Decide what message is necessary to send or which mistakes you want to prevent from happening. During this step it is really important to identify communication at all levels
2. Design a simple visual "tool" to clearly communicate your message (colored lines, colored bins; visual dashboard; Andon; Kanban card, gage, checklist etc.). It is necessary to involve people
3. Test the visual impact on people and ask for feedback from those involved
4. Make all the adjustments or changes necessary to improve the communication effects

Lean6σ

Visual Management

Visual Management examples:

Not standard condition: the material rack is not in the designated place

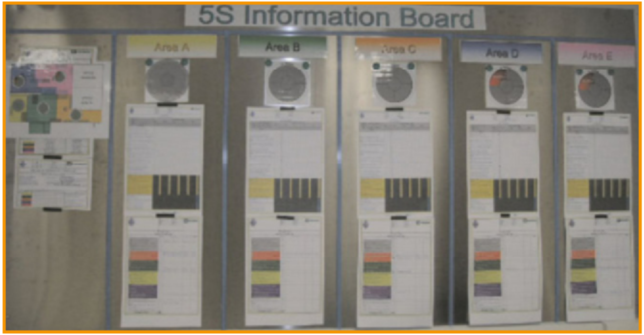
Standard condition: the material rack is in its designated place

Files are organized with colored labels (each color represents a different year)

Blue bins indicate raw material. Yellow bins indicate WIP materials

Visual Management

Visual Management examples:

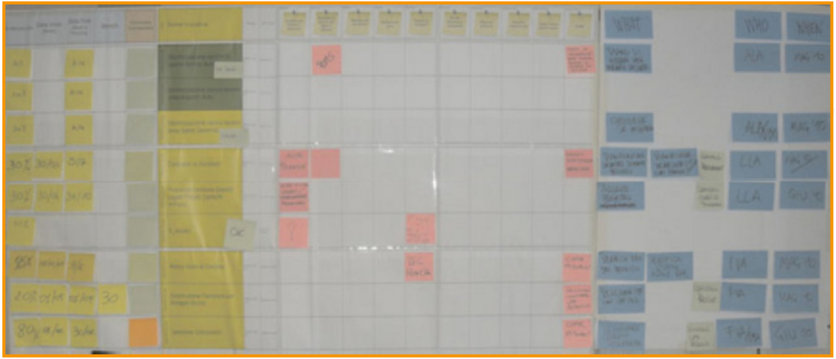


5S Dashboard: the information board allows employees at all levels to see the 5S status for each area in which 5S method is implemented

Red lines and labels indicate a place where scrap parts are segregated

Visual Management

Visual Management examples:

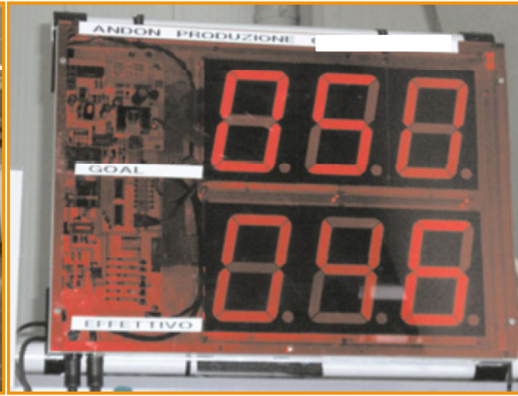


Strategy deployment activity board: Team department dashboard to assess the follow up phase of the annual strategy deployment cycle

Visual Management

Visual Management examples:

Manufacturing cell information board



"Andon (G)" for production control

OPL - One Point Lesson

Objective:

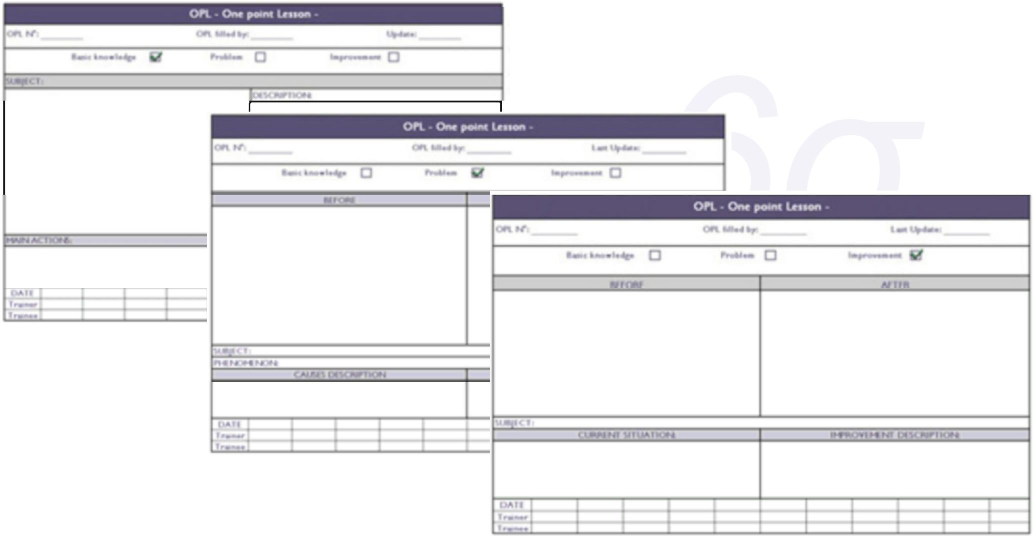
- The One Point Lesson (OPL[G]) is a method that allows a rapid and effective transfer of information from the leader of a group to its members. It must be written as simple as possible and should follow the 80-20 rule and use 80% pictures and 20% words (or less). The lesson should take from 5 to 10 minutes

Types of OPL:

- **Basic information One Point Lesson**: used to transfer essential basic information, practical know-how and know-how of methods
- **Problem/Defect One Point Lesson**: used to teach how to prevent occurrence of a specific problem
- **Improvement/Kaizen**: describes the main characteristic and key measures in an improvement activity

OPL - One Point Lesson

One point lesson formats



OPL - One Point Lesson

Why is OPL important?

- To train people fast on a precise item
- To strengthen their understanding of the functions of machines, lines and processes in general (both manufacturing and transactional)
- To teach people about specific problems/defects in the process in order to eliminate their occurrence

Who should use the OPL?

- Team leader or process expert

Where should the OPL activities happen?

- At the "Gemba" (shopfloor, next to the machine, next to the computer in the case of software training, etc.)

OPL - One Point Lesson

One point lesson example

OPL - One point Lesson -

OPL N°: 21   OPL filled by: Mr.White   Last Update: 23-feb-09

Basic knowledge ☐   Problem ☐   Improvement ☑

BEFORE	AFTER
	

SUBJECT: Optimization of laboratory materials

CURRENT SITUATION:	IMPROVEMENT DESCRIPTION:
The engines for the laboratory tests do not have a precise location and are not easily distinguishable at first sight EFFECT: Too much time wasted in finding the right engine to test and loss of productivity (No. of tests/day) → 20 tests/day	ACTION: Classification and labeling of engines for the test; engines placed on shelves for easy identification EFFECT: Increase the numbers of tests per day → 23 tests / day (+15%)

DATE											
Trainer											
Trainee											

OPL - One Point Lesson

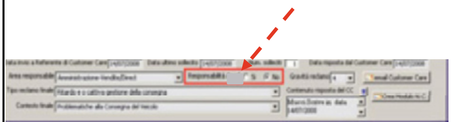
One point lesson example

OPL - One Point Lesson -

OPL N°: 2 **OPL filled by:** Mr.Green **Update:** 31. Jul 08

Basic knowledge ☑ **Problem** ☐ **Improvement** ☐

SUBJECT:



DESCRIPTION:

Procedure for the correct allocation of responsibility in a complaint

MAIN ACTIONS:

Select "YES" if the complaint responsibility is attributable to XYZ; select "NO" if the complaint is not of XYZ's responsibility.

ATTENTION: Assign the responsibility of the complaint only if after receiving the response from the department DC

DATE											
Trainer											
Trainee											

Lean Six Sigma Checklist

Arcidiacono G., Calabrese C., Yang K.: Leading processes to lead companies: Lean Six Sigma.
DOI 10-1007/978-88-470-2492-2, © Springer-Verlag Italia 2012

Define Checklist

Some steps to check *Define* phase completion:

	Project selected with *Sponsor*
	Business Case identified
	Process identified
	Customer/s identification completed
	Team Leader choosen (Green Belt/Black Belt; internal/External)
	Team Member defined
	Project scope identified
	Project constraints identified and examined
	VOC (Voice of Customer) identified
	CTQs defined (SMART)
	SIPOC developed
	"As is" process mapping built and shared
	Benefit estimation (hard and soft savings) defined
	Waste properly identified
	Project Charter completed and shared with Sponsor

✔ = Activity completed

Measure Checklist

Some steps to check *Measure* phase completion:

	Output operative definition identified
	Xs (potential input variables) to be measured identified
	Xs operative definition identified
	Setup of data collection plan
	Measurement system validated (Are the data reliable?)
	Data collection implemented and completed
	Basic statistics analysis & Trend analysis completed
	Process Capability
	Process performance identified (OEE; Takt time; Process Sigma; etc.)
	Measure phase shared with Sponsor

Analyze Checklist

Some steps to check *Analyze* phase completion:

	QUALITATIVE ANALYSIS
☐	Potential root causes defined
☐	Stratification factors explored
☐	Process mapping analysis completed
☐	"Root causes" identified
	QUANTITATIVE ANALYSIS
☐	Significance of root causes validated, "Vital Few" identified (Regression, Hypothesis Testing)
☐	Analyze phase and global project review shared with Sponsor

Improve Checklist

Some steps to check *Improve* phase completion:

☐	Solution generation (DOE, Creative Thinking; Lean applications)
☐	Solution evaluation completed
☐	Optimal solution identified and shared with Sponsor
☐	Lean application implemented (5S; Standard Work; Kanban; etc.)
☐	Pilot and check completed
☐	Pilot: potential risks identified
☐	Solution implementation validated
☐	Improve phase shared with Sponsor

Control Checklist

Some steps to check *Control* phase completion:

	Standard procedure for CTQs monitoring implemented (Control plan)
	Standard procedures documented
	Visual management and error proofing systems set and implemented
	Potential improvement areas identified (Continuous Improvement)
	"Lesson Learned" prepared
	Final project review with Sponsor
	Project closure
	Summarized project documentation completed
	Extended project documentation completed
	Celebration

APPENDIX A: Process Sigma Table (I)

Yield	DPMO	Sigma
6,68072%	933.193	0,00
7,35293%	926.471	0,05
8,07567%	919.243	0,10
8,85080%	911.492	0,15
9,68005%	903.200	0,20
10,56498%	894.350	0,25
11,50697%	884.930	0,30
12,50719%	874.928	0,35
13,56661%	864.334	0,40
14,68591%	853.141	0,45
15,86553%	841.345	0,50
17,10561%	828.944	0,55
18,40601%	815.940	0,60
19,76625%	802.337	0,65
21,18554%	788.145	0,70
22,66274%	773.373	0,75
24,19637%	758.036	0,80
25,78461%	742.154	0,85
27,42531%	725.747	0,90
29,11597%	708.840	0,95

Yield	DPMO	Sigma
30,85375%	691.462	1,00
32,63552%	673.645	1,05
34,45783%	655.422	1,10
36,31693%	636.831	1,15
38,20886%	617.911	1,20
40,12937%	598.706	1,25
42,07403%	579.260	1,30
44,03823%	559.618	1,35
46,01722%	539.828	1,40
48,00612%	519.939	1,45
50,00000%	500.000	1,50
51,99388%	480.061	1,55
53,98278%	460.172	1,60
55,96177%	440.382	1,65
57,92597%	420.740	1,70
59,87063%	401.294	1,75
61,79114%	382.089	1,80
63,68307%	363.169	1,85
65,54217%	344.578	1,90
67,36448%	326.355	1,95

Yield	DPMO	Sigma
69,14625%	308.538	2,00
70,88403%	291.160	2,05
72,57469%	274.253	2,10
74,21539%	257.846	2,15
75,80363%	241.964	2,20
77,33726%	226.627	2,25
78,81446%	211.855	2,30
80,23375%	197.663	2,35
81,59399%	184.060	2,40
82,89439%	171.056	2,45
84,13447%	158.655	2,50
85,31409%	146.859	2,55
86,43339%	135.666	2,60
87,49281%	125.072	2,65
88,49303%	115.070	2,70
89,43502%	105.650	2,75
90,31995%	96.800	2,80
91,14920%	88.508	2,85
91,92433%	80.757	2,90
92,64707%	73.529	2,95

APPENDIX A: Process Sigma Table (II)

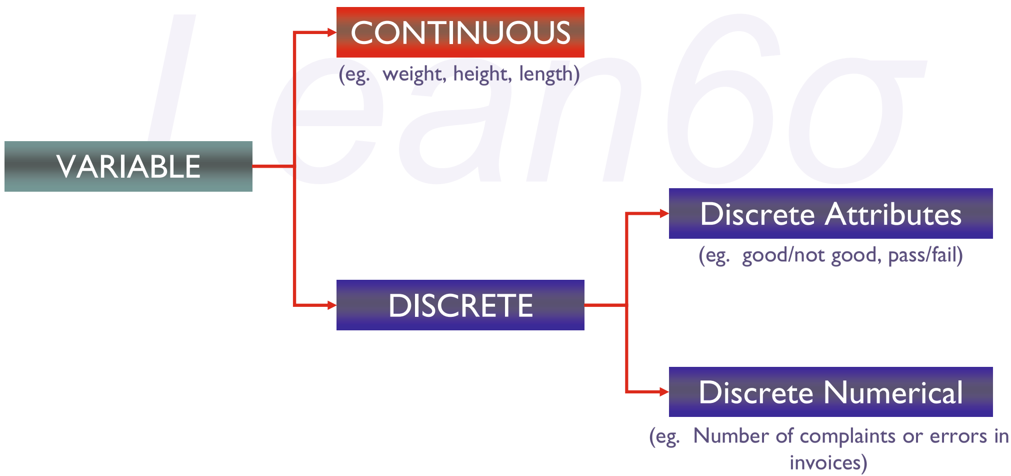
Yield	DPMO	Sigma
93,31928%	66.807	3,00
93,94292%	60.571	3,05
94,52007%	54.799	3,10
95,05285%	49.471	3,15
95,54345%	44.565	3,20
95,99408%	40.059	3,25
96,40697%	35.930	3,30
96,78432%	32.157	3,35
97,12834%	28.717	3,40
97,44119%	25.588	3,45
97,72499%	22.750	3,50
97,98178%	20.182	3,55
98,21356%	17.864	3,60
98,42224%	15.778	3,65
98,60966%	13.903	3,70
98,77755%	12.224	3,75
98,92759%	10.724	3,80
99,06133%	9.387	3,85
99,18025%	8.198	3,90
99,28572%	7.143	3,95

Yield	DPMO	Sigma
99,37903%	6.209,7	4,00
99,46139%	5.386,1	4,05
99,53388%	4.661,2	4,10
99,59754%	4.024,6	4,15
99,65330%	3.467,0	4,20
99,70202%	2.979,8	4,25
99,74449%	2.555,1	4,30
99,78140%	2.186,0	4,35
99,81342%	1.865,8	4,40
99,84111%	1.588,9	4,45
99,86501%	1.349,9	4,50
99,88558%	1.144,2	4,55
99,90324%	967,6	4,60
99,91836%	816,4	4,65
99,93129%	687,1	4,70
99,94230%	577,0	4,75
99,95166%	483,4	4,80
99,95959%	404,1	4,85
99,96631%	336,9	4,90
99,97197%	280,3	4,95

Yield	DPMO	Sigma
99,97674%	232,6	5,00
99,98074%	192,6	5,05
99,98409%	159,1	5,10
99,98689%	131,1	5,15
99,98922%	107,8	5,20
99,99116%	88,4	5,25
99,99277%	72,3	5,30
99,99409%	59,1	5,35
99,99519%	48,1	5,40
99,99609%	39,1	5,45
99,99683%	31,7	5,50
99,99744%	25,6	5,55
99,99793%	20,7	5,60
99,99834%	16,6	5,65
99,99867%	13,3	5,70
99,99893%	10,7	5,75
99,99915%	8,5	5,80
99,99932%	6,8	5,85
99,99946%	5,4	5,90
99,99957%	4,3	5,95
99,99966%	3,4	6,00

APPENDIX B: Kinds of variables

This summary could be useful for the correct selection of indicators during the implementation of a Lean Six Sigma project



APPENDIX C: Kaizen Leader Standard Form

Waste Walk Analysis format example

"Waste Walk Format"

Company: ____________ Product/Practice followed: ____________

Observer: ____________ Date: ____________

Waste category	Process Step	Waste Comment	Waste estimation	Possible idea/solution

APPENDIX C: Kaizen Leader Standard Form

5S format example

5S Program Areas

PLANIMETRY...

#	AREA	AREA RESPONSIBLE	DEPUTY-RESPONSIBLE	TEAM
1	Pink			
2	Heavenly			
3	Green			
4	Blue			
5	Orange			
6	Yellow			
7	Grey			
8	Brown			
9	White			

APPENDIX C: Kaizen Leader Standard Form

5S format example

Audit team and calendar

Steering team members:

Plant Manager: ....

Project Sponsor: ....

Lean coordinator: ....

Functional manager: ....

Department manager: ....

#	AREA	G	F	M	A	M	J	L	A	S	O	N	D	Notes
1	Pink													For each area, the audit teams should be built as follows: - Area responsible - External area responsible - Two members of the steering team
2	Heavenly													
3	Green													
4	Blue													
5	Orange													
6	Yellow													
7	Grey													
8	Brown													
9	White													

APPENDIX C: Kaizen Leader Standard Form

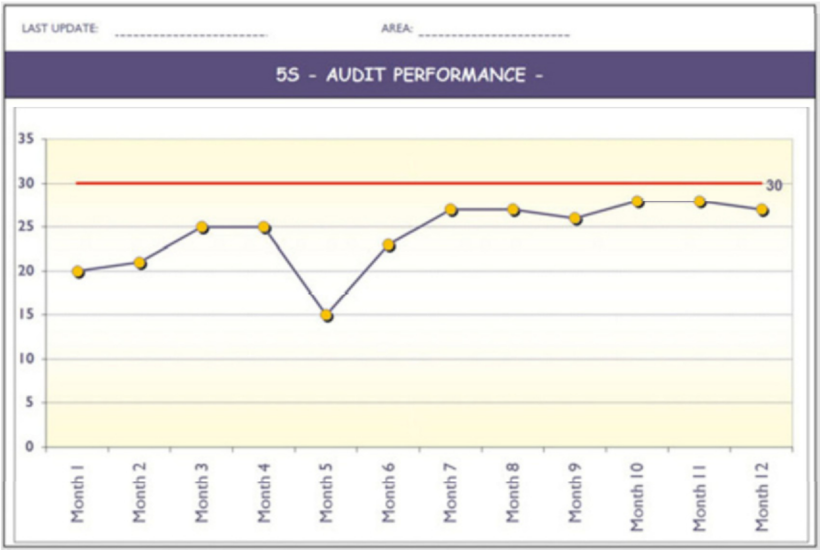
5S format example

5S Audit Form
5S Assessment format

N.		Action	"OK" = 1 "KO" = 0	Corrective Action	Who	When
1	1L - SAFETY	Are all workers in the area using Individual Safety Devices, when needed?				
2		Fire extinguishers are marked and easily accessible?				
3		The escape routes and emergency exits are marked and accessible?				
4		There are devices to prevent accidents on equipment/machine used?				
5		The machines are turned off if not used?				
6	1S - SORT	Have unnecessary objects been thrown away or segregated?				
7		Are the objects needed in the workplace properly identified?				
8		Are aisle/walk ways and workstations clearly marked and identified on the floor?				
9		Are there any safety data sheet for chemicals products?				
10		Are heavy objects placed in safe position in order to avoid any risk of injury?				
11	2S - SET IN ORDER	Are equipment, electrical cables and panels in good condition?				
12		Are the machines equipped with use and maintenance manual?				
13		Are objects placed close to the "point of use" and according to "frequency of use"?				
14		Are all items well visually organized and placed in the assigned position?				
15		Are the positions of tools, materials and objects labeled?				
16	3S - SHINE	Are chemicals and wastes properly stored?				
17		Are equipment and cleaning materials in the vicinity of the workstations?				
18		Are the workplaces and floors free from obstructions so to not fall?				
19		Are machineries and tools clean and free of dirt, oil, grease, dust and waste?				
20		Is the floor free from dirt, oil, grease, scrap and scraps products?				
21	4S - STANDARDISE	Have dispositions been given for keeping the first 3S?				
22		Have dispositions been given on safety?				
23		Are all objects in the workplace in standard condition?				
24		Are responsibles using the checklist to verify 5S objectives?				
25		Are there any labels indicating the temperature, pressure, voltage of critical components?				
26	5S - SUSTAIN	Are audit performed regularly?				
27		Are audits performed by personnel external to the area?				
28		Is the area checklist properly applied by responsibles and relative teams?				
29		Is there a corrective action plan for the area ("what to do", "Who","when")?				
30		Is the 5S information board put in place with division into areas, scores, corrective actions and updated?				
		TOTALE SCORE	0			

APPENDIX C: Kaizen Leader Standard Form

5S format example



APPENDIX C: Kaizen Leader Standard Form

Standard Work: Cycle Time Observation Form

Observation Date		Kaizen Leader	
Company		Kaizen Team	
Kaizen			
Observation Time			
Process			

Cycle Time Observation Form

N.	Task	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Mean	Lowest repeatable	Standard time
1														
2														
3														
4														
5														
6														
7														
8														
9														
	Cycle time (1 Cycle)	0	0	0	0	0	0	0	0	0	0			0

APPENDIX C: Kaizen Leader Standard Form

Standard Work: Process Capacity Form

Observation Date		Opearting time per shift	
Company		Shift No	
Part No		Daily demand	
Process		Supervisor	

Process Capacity Form

Step #	Process Description	Machine	Base Time		Tool Change			Total Time (sec.)	Processing Capacity	Remarks
			Manual Time (sec.)	Machine Time (sec.)	# Pieces /Change	Change Time	Tool Change Time (sec.)			
1										
2										
3										
		Total:	0					Maximum daily production:	0	

APPENDIX C: Kaizen Leader Standard Form

Standard Work: Standard Work Combination Form

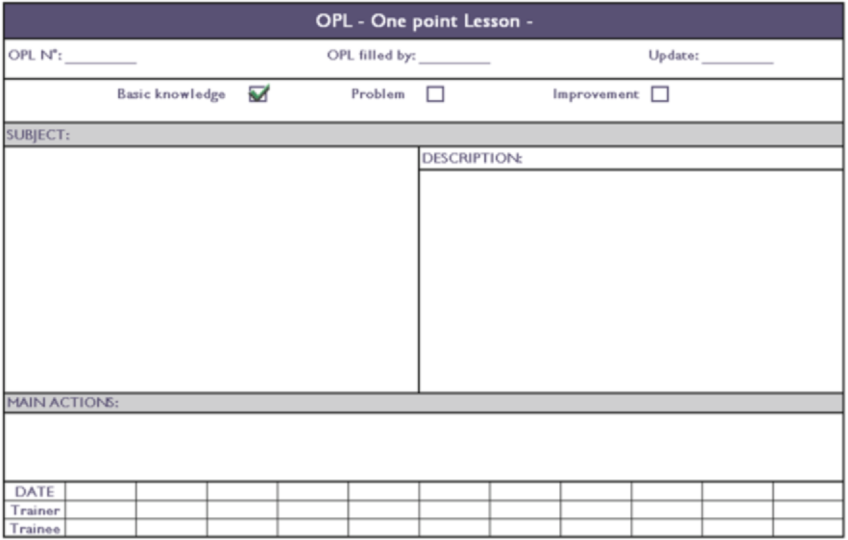
Observation Date		Opearting time per shift		- - - = Machine
Company		Daily demand		= Manual
Part No		Takt Time (ses)		= Walking
Process		Supervisor		= Takt Time

Standard Work Combination Form

Step #	Task/Activity Description	Time			Operation Working Time (secs)																				
		Man.	Auto	Walk	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105
1																									
2																									
3																									
4																									
5																									
6																									
7																									
8																									
9																									
10																									
11																									
12																									
13																									

APPENDIX C: Kaizen Leader Standard Form

OPL - Basic information



OPL - One point Lesson -

OPL N°: ________ OPL filled by: ________ Update: ________

Basic knowledge ☑ Problem ☐ Improvement ☐

SUBJECT:

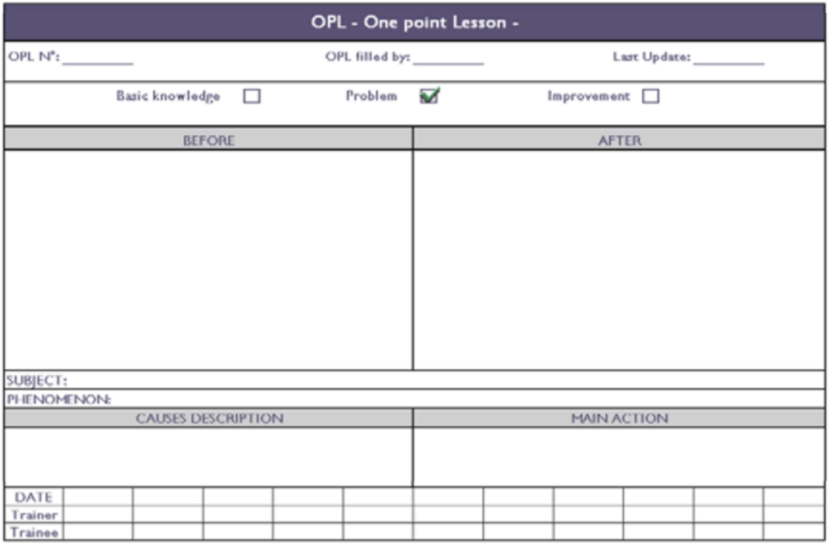
DESCRIPTION:

MAIN ACTIONS:

DATE											
Trainer											
Trainee											

APPENDIX C: Kaizen Leader Standard Form

OPL - Problem/Defect


OPL - One point Lesson -

OPL N°: __________ OPL filled by: __________ Last Update: __________

Basic knowledge ☐ Problem ☑ Improvement ☐

BEFORE	AFTER

SUBJECT:

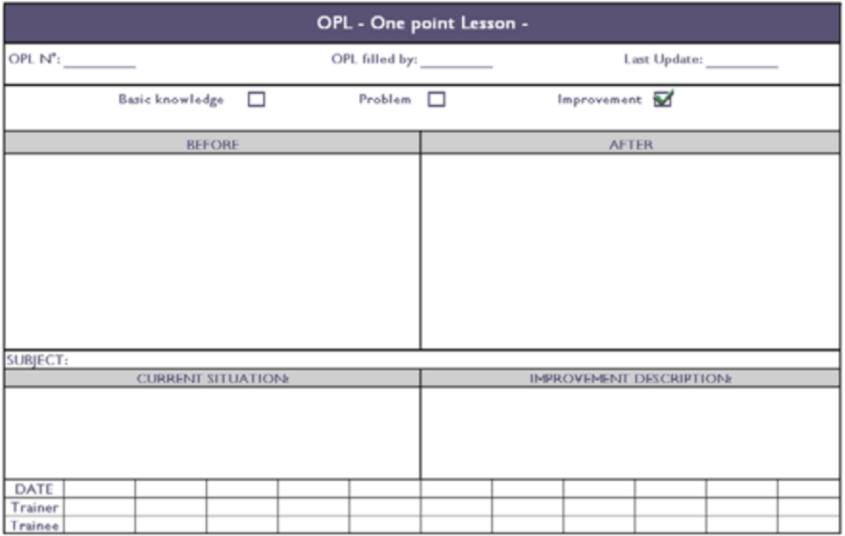
PHENOMENON:

CAUSES DESCRIPTION	MAIN ACTION

DATE											
Trainer											
Trainee											

APPENDIX C: Kaizen Leader Standard Form

OPL - Improvement/Kaizen



OPL - One point Lesson -

OPL N°: ________ OPL filled by: ________ Last Update: ________

Basic knowledge ☐ Problem ☐ Improvement ☑

BEFORE	AFTER

SUBJECT:

CURRENT SITUATION:	IMPROVEMENT DESCRIPTION:

DATE											
Trainer											
Trainee											

APPENDIX C: Kaizen Leader Standard Form

Kaizen Newspaper example:

Kaizen event date	20 March 2009
Company	ABC Company
Place	XXX
Kaizen	Changeover reduction
Kaizen Leader	Mr. Green
Kaizen Team	Mr. Green; Mr. Yellow; Mrs. Orange; Mr. Blue; Mr. White
Last Update	30 March 2009
% Kaizen	48%

Kaizen Newspaper

N.	Action	Who	Start date	Expected end date	End date	Priority	Status	Notes
1	Identify which families are more products on production line	Mr. Green	March 20	March 23	March 23	A	100%	
2	Determine which materials should be at each workstation	Mr. Yellow	March 20	March 27		A	56%	
3	Eliminate all the things not necessary	Mr. White	March 20	March 21	March 22	A	100%	
4	Identify which kind of bin should be used to manage the different part	Mr. Yellow	March 20	April 4		A	70%	Purchased n°30 bins model B; n°86 bins for small parts
5	Create workstation Before/After	Mr. Yellow	March 20	April 4		A	95%	
6	Label on the floor all the workstations	Team	March 20	April 15		B	0%	
7	Optimal layout study	Mr.Blue	March 20	April 15		C	0%	

APPENDIX C: Kaizen Leader Standard Form

Kaizen performance:

Kaizen event date	25 May 2009
Company	ABC Company
Place	XXX
Kaizen	Changeover reduction
Kaizen Leader	Mr. Green
Kaizen Team	Mr. Green; Mr. Yellow; Mrs. Orange; Mr. Blue; Mr. White
Last Update	30 March 2009
% Kaizen	95%

Kaizen Performance

N.	Measurement	UoM	Before Kaizen	Kaizen Goal	After Kaizen	After 2 Weeks	After 4 Weeks	After 6 Weeks	After 8 Weeks
1	Productivity	Pcs/Hours							
2	Space reduction	m^2							
3	Walking distance	m							
4	Batch size	Pcs							
5	**Set up time**	Min	79'	30'	40'	25'	25'	22'	27'
6	Cycle time	Min/secs							
7	OEE	%							
8	Savings	(€)							
9	Lead Time (gg)								
10	Inventory turn								
11	5S Score								

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Glossary

A

Andon: Andon is any visual indicator signaling the current status of a step in the production/process system. It alerts team leaders or supervisors in case of existing or emerging production/process problems.

B

Brainstorming: A group based creativity technology that is designed to generate and select ideas for problems solving.

BVA, Business Value Added activity: Activity that does not add any value to the product/service but is necessary from a business operations' point of view.

C

Cell: It is a workplace in which equipment, people, machinery, materials and methods are arranged in order to have continuous production flow.

Confidence Interval (CI): is the interval which, with a likely probability, contains the mean (or proportion, median, standard deviation) of the population, where the sample comes from.

Common Cause: The cause, random in nature and not related to any special event, is behind natural inherent variability displayed in processes.

COPQ, Cost Of Poor Quality: COPQ are the costs related to poor performance of manufacturing or transactional processes.

CTQ, Critical To Quality: The key measurable features of a product or process whose performance standards or specification limits must be met in order to satisfy the customer.

Customer: The client, internal or external, is the recipient of a process / product / service.

Customer Satisfaction: is a measure of how products and services supplied by a company meet customer expectation. Customer expectation should be objectively and accurately measured by collecting and analyzing "Voice Of the Customer" (VOC). It is the starting point for identifying improvements.

D

DMAIC: Stands for 5 phases of Lean Six Sigma methodology: **D**efine, **M**easure, **A**nalyze, **I**mprove, **C**ontrol.

DOE, Design Of Experiment: DOE is a methodology that builds, through well-planned experiments and analysis of the experimental results, the analytical model relating to the cause-effect relationship between input and output variables.

DPMO, Defects Per Million of Opportunity: DPMO is a performance indicator calculated as a ratio of number of defects divided by maximum number of potential defects in a batch of units inspected.

Glossary

F

FMEA, Failure Modes and Effects Analysis: FMEA is a tool that can be used to identify a detailed list of failure modes of a product or process and their corresponding causes and then rate them with a severity level, a likelihood of occurrence and detection in order to manage the system risk.

H

Heijunka: is one of the elements of Just in Time and it is the process of smoothing the type and quantity of production over a fixed period of time.

J

Jidoka: This term means "automation with human intelligence". It means that an automated process is sufficiently "aware" of itself so that it will detect process malfunctions or product defects, stop itself and alert the operator.

K

Kaizen: means "to become good through change". A Kaizen event is a focused effort for make an improvement activity.

Kanban: It is a method used in many applications in various processes. It is primarily used as an instruction mechanism that controls the production, movement of goods, material, or parts, or jobs.

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L

LCL, Lower Control Limit: Represents the lower limit of a stable distribution for the variability of a process (VOP).

Lead Time: is the time between the placing of an order and the receipt of goods/services ordered (it is also possible to speak about Production Lead Time, Delivery Lead Time etc.).

Lean: is the methodology that aims to identify and eliminate wastes in order to maximize speed and flexibility of business processes so we can deliver what is needed, when needed and in the quantity needed by the Customer.

LSL, Lower Specification Limit: Represents the lower limit of a tolerance region that is acceptable by the customer.

N

NVA, Non Value Added activity: Activity that does not add any value to the product/service.

O

OEE, Overall Equipment Effectiveness: is a powerful method to monitor and improve the efficiency of manufacturing and transactional processes.

OPL, One Point Lesson: is a method that allows a rapid and effective transfer of information from the leader of a group to its members.

Outlier: An observation that is numerically distant from the rest of the data.

P

Poka Yoke: It is one of the techniques that aims to reach the "Zero Defect Quality" through the usage of devices or procedures, which allows detection of an error that could lead to waste.

Process Capability Analysis: Also called Capability Analysis, is a performance index used to measure the ability of a process (VOP) to meet the specification limits defined by customers (VOC).

Process Owner: is the owner of the process, usually the head of a department or office in which the Lean Six Sigma project is implemented.

Process Sigma: Process Sigma is a performance metric that is based on comparing specification length with the standard deviation (Sigma) of process. This performance index is related to defective rates.

Project Charter: is a document which contains key information on implementing a Lean Six Sigma project.

P-Value: is a measure of how much evidence we have against the importance of a factor. The smaller the P-Value, the stronger the evidence. A P-Value of < 0.05 is an indication of statistically significant evidence.

Glossary

R

Rational subgroups: The rational subgroups are samples chosen in a way that maximize the variability between samples when there are special causes present and the variability within the sample is minimized.

Reorder Point (ROP): is the inventory level of an item which signals the need for placement of a replenishment order, taking into account the consumption of the item during order Lead Time and the quantity required for safety stock.

Residual: Difference between actual value of data and predicted value from mathematical models (derived by Regression or Design Of Experiments).

S

Savings: Economic or strategic benefits resulting from improvement/project activities.

SIPOC: High level process mapping to describe any kind of process (Supplier, Input, Process, Output, Customer).

Standard Work: It is the most effective combination of manpower, materials and machinery to produce something in the time, quality and quantity required by customer.

Glossary

Six Sigma: A well structured and disciplined operating strategy (structured according to the DMAIC phases), to measure, analyze and improve the performance in terms of operational excellence. The Six Sigma methodology is sufficiently flexible and adaptable to different business contexts.

SMED: **S**ingle **M**inute **E**xchange of **D**ie is a method that aims to reduce the changeover time of equipment, machine or a production/service process in general.

Special Cause: The cause that is often associated with a special event and the result of a special cause often lets the process form a trend, seasonality or other non random patterns.

T

Takt Time: It represents the rhythm of production/delivery that a process (workstation, Cell, etc.) must respect to satisfy customer demand.

U

UCL, Upper Control Limit: Represents the upper limit of a stable distribution for the variability of a process (VOP).

USL, Upper Specification Limit: Represents the upper limit of a tolerance region that is acceptable by the customer.

Glossary

V

VA, Value Added activity: An activity that increases the value of the product/service from the customer's point of view. It is something that customers are willing to pay for.

Visual Management: It is a method that makes all processes within a company visual and tangible.

VOC, Voice Of The Customer: The "Voice of the Customer" is how the customer perceives the product/process/service in comparison with their desires.

VOP, Voice Of Process: The "Voice of the Process" is what the process/product/service is able to deliver.

VSM, Value Stream Mapping: It is a diagram of every step involved in the material and information flow necessary to bring the product/service from the order to delivery phase.

W

Waste: It is the use of resources (time, material, labor, etc.) for doing something that the customers are not willing to pay for and, therefore, does not add value to the product or service provided.

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