Lean Six Sigma
Pre-Course Study Material

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1 Six Sigma Overview

1.1 What is Six Sigma?

Sigma is the Greek letter representing a statistical unit of measurement that defines the standard deviation of a population. It measures the variability or spread of the data. The lower the variability in a process, the more of the process outputs, products and services, meet customers' requirements – or, the fewer the defects.

Six Sigma is a **vehicle for strategic change** ... an organizational approach to performance excellence. Six Sigma is important for business operations because it can be used both to increase top-line growth and also reduce bottom line costs. Six Sigma can be used to enable:

1. **Transformational change** by applying it across the board for large-scale fundamental changes throughout the organization to change processes, cultures, and achieve breakthrough results.

2. **Transactional change** by applying tools and methodologies to reduce variation and defects and dramatically improve business results.

When people refer to Six Sigma, they refer to several things:

- It is a philosophy
- It is based on facts & data
- It is a statistical approach to problem solving.
- It is a structured approach to solve problems or reduce variation
- It refers to 3.4 defects per million opportunities
- It is a relentless focus on customer satisfaction
- Strong tie-in with bottom line benefits

The two most common used methodologies are DMAIC & DMADV[1]:

1. **DMAIC: Define, Measure, Analyse, Improve and Control**

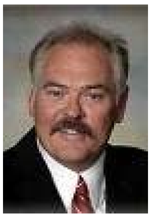
    - Structured and repeated process improvement methodology
    - Focus on defects reduction
    - Improvements in existing products and processes

[1] Some companies use an equivalent methodology called IDOV (Identify – Design – Optimize – Verify)

2. **DMADV: Define, Measure, Analyse, Design, Verify/Validate**
    - Strict approach to design process to exceed customer expectations
    - Focus on preventing errors and defects.
    - Develop new product/ process, or redesign existing product/ process.
    - If DMAIC does not produce sufficient improvements, we use DMADV.

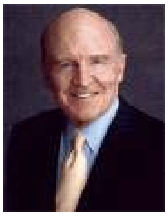
1.2 History of Six Sigma

In the late 1970's, Dr. Mikel Harry, a senior staff engineer at Motorola's Government Electronics Group (GEG), experimented with problem solving through statistical analysis. Using this approach, GEG's products were being designed and produced at a faster rate and at a lower cost. Subsequently, Dr. Harry began to formulate a method for applying Six Sigma throughout Motorola. In 1987, when Bob Galvin was the Chairman, Six Sigma was started as a methodology in Motorola. Bill Smith, an engineer, and Dr. Mikel Harry together devised a 6 step methodology with the focus on defect reduction and improvement in yield through statistics. Bill Smith is credited as the father of Six Sigma. Subsequently, Allied Signal began implementing Six Sigma under the leadership of Larry Bossidy. In 1995, General Electric, under the leadership of Jack Welch began the most widespread implementation of Six Sigma.


Dr. Mikel Harry


Bill Smith


Larry Bossidy


Jack Welch

General Electric: "It is not a secret society, a slogan or a cliché. Six Sigma is a highly disciplined process that helps focus on developing and delivering near-perfect products and services. Six Sigma has changed our DNA – it is now the way we work."

Honeywell: "Six Sigma refers to our overall strategy to improve growth and productivity as well as a quality measure. As a strategy, Six Sigma is a way for us to achieve performance breakthroughs. It applies to every function in our company and not just to the factory floor."

The tools used in Six Sigma are not new. Six Sigma is based on tools that have been around for around for centuries. For example, Six Sigma relies a lot on the normal curve which was introduced by Abraham de Moivre in 1736 and later popularized by Carl Friedrich Gauss in 1818.

1.3 Key Business Drivers

The Key Performance Indicators (KPIs) that are tracked by businesses to measure its progress towards strategic objectives is usually displayed together on a scorecard. This scorecard is reviewed by management on at least a monthly basis to identify problem areas and take corrective actions as needed. There are four primary areas within a scorecard: Financial, Customer, Internal Business Processes, and Learning & Growth. Some indicators are lagging indicators in the sense that they talk about what has already occurred. An example of a lagging indicator is Revenue in the last quarter. It can be an important indicator for the business to know about but it does not tell the full story of what is going to happen in the future. Hence, scorecards must also contain indicators that predict future performance. These indicators are called leading indicators. For example, if we know that all employees are trained 20 hours this year, this could be a leading indicator of future employee performance. Following are some traditional KPIs that businesses track within their scorecard:

Financial Indicators

- Revenue (amount of money collected by selling products or services)
- Cost of Goods Sold (amount of money expended to produce products or services)
- Gross Income (difference between Revenue & Cost of Goods Sold)
- Net Income (profitability of the company after subtracting all expenses)
- Percentage of Industry Sales (PINS – indicator of market share)
- Earnings per Share (EPS – Net income divided by number of outstanding shares. Indicator of return earned by each shareholder)
- Cash Flow (Amount of money earned vs. spent during the indicated period)

Customer Indicators

- Customer Returns (Amount of $$ returned by customers – an indicator of how satisfied customers are with products/services)
- Warranty (More the money spent on warranty, less satisfied are the customers)
- Net Promoter Score (NPS – will our customers recommend us to others based on survey results)
- On-time delivery (% of products/services delivered on-time)
- Number of Complaints Received
- Customer Churn

Internal Business Processes

- Efficiency (Productivity indicator for key resources)

- New Product Introduction Cycle Time (Time taken for development of new products)
- Net Revenue by Product (Indicator of which products contribute to revenue – some companies may require new products generate at least 20% revenue)
- Material or Production Costs
- Quality Indicators (Rework)
- Production Cycle Time

Learning & Growth

- Training per Employee
- Labour Productivity
- Staff Turnover
- Speed of Promotion
- Six Sigma or Lean Benefits

1.4 Six Sigma Project Selection Process

Ideally, Green Belts and Black Belts are expected to work on projects and are not directly responsible for generation or selection of Six Sigma projects. Six Sigma projects are selected by senior management on certain criteria. These criteria include linkage between the proposed project and company strategy, expected timeline for project completion, expected revenue from the projects, whether data exists to work on the problem, whether the root cause or solution is already known. Table 1 shows a typical project selection template used by management to pick projects. The projects that have the highest net score are the ones that get picked for execution.

Number	Sponsor	Project Description	Costs	Benefits	Timeline	Strategy	Risk	Score
1	Jim Smith	Reduce inventory levels for 123 series products	0	1,00,000	6 months	High	Low	4.4
2	Bob Bright	Improve efficiency for Machine 456-2333	5000	2,00,000	6 months	Med	Low	5.0
3	John Travolta	Improve employee retention by 5%	0	40,000	3 months	High	Med	4.0
4	Peter Hunt	Reduce cycle time for making products	1000	1,00,000	1 year	Med	Low	3.4
5	Bill Richards	Improve customer satisfaction scores	0	0	1 year	High	Low	2.8

Table 1: Example Project Selection Template

For a project to be a valid Six Sigma project it must be a chronic issue, it must have an unknown root cause and unknown solution. For if the solution is already known, there is no point wasting everyone’s time to do data analysis and determine the root cause and solution. All that is needed is to just do the implementation of the solution.

2 Lean Principles Overview

Lean is a philosophy that seeks to minimize the working capital required to produce a product or provide a service. In other words, the value added time through a process should dramatically outweigh the non-value added time. Lean is all about **eliminating wastes** from a process and **making the product or service flow**.

Lean focuses on waste elimination while Six Sigma focuses on reduction of variation. Lean Six Sigma is the application of the DMAIC methodology, supplemented with concepts extracted from the principles of lean. Combined together, they provide a sustainable process for increasing velocity, managing inventory/capacity and reducing waste. Following are some basic overview of Lean tools & principles:

2.1 What is 5S?

5S is a process and method for creating and maintaining an organized, clean, and high performance workplace. 5S enables anyone to distinguish between normal and abnormal conditions at a glance. 5S is the foundation for continuous improvement, zero defects, cost reduction, and a safe work area. 5S is a systematic way to improve the workplace, our processes and our products through production line employee involvement. 5S can be used in Six Sigma for quick wins as well as control. 5S should be one of the Lean tools that should be implemented first. If a process is in total disarray, it does not make sense to work on improvements. The process needs to be first organized (stabilized) and then improved.

The 5 S's are:

1. Sort – Clearly distinguish needed items from unneeded items and eliminate the latter.
2. Straighten / Stabilize / Set in Order – Keep needed items in the correct place to allow for easy and immediate retrieval
3. Shine – Keep the work area clean
4. Standardize – Develop standardized work processes to support the first three steps
5. Sustain – Put processes in place to ensure that that the first four steps are rigorously followed.

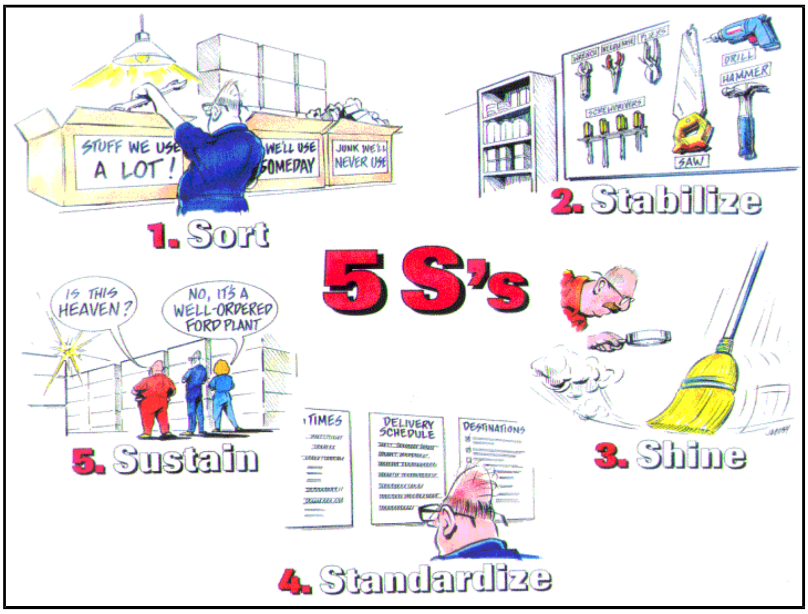


Figure 1: 5S Image from www.tpfeurope.com

2.2 *What is Kaizen?*

Kaizen is a Japanese word that means to break apart to change or modify (Kai) to make things better (Zen). Kaizen is used to make small continuous improvements in the workplace to reduce cost, improve quality and delivery. It is particularly suitable when the solution is simple and can be obtained using a team based approach. Kaizen assembles small cross-functional teams aimed at improved a process or problem in a specific area. It is usually a focussed 3-5 day event that relies on implementing "quick" and "do-it-now" type solutions. Kaizen focuses on eliminating the wastes in a process so that processes only add value to the customer. Some of the 7 wastes targeted by Kaizen teams are:

- Waiting/Idle Time/Search time (look for items, wait for elements or instructions to be delivered)
- Correction (defects/rework & scrap - doing the same job more than once)
- Transportation (excess movement of material or information)
- Over-production (building more than required)
- Over-processing (processing more than what is required or sufficient)
- Excess Motion (excess human movements at workplace)
- Storage/warehousing (excess inventory)

The benefits of doing Kaizen are less direct or indirect labour requirements, less space requirements, increased flexibility, increased quality, increased responsiveness, and increased employee enthusiasm. Figure 2 shows a Kaizen team in action discussing improvements.

Figure 2: A Kaizen Team at Boeing in Action

2.3 What is Poka-Yoke?

Poka-yoke is a structured methodology for mistake-proofing operations. It is any device or mechanism that either prevents a mistake from being made or ensures that the mistakes don't get translated into errors that the customers see or experience. The goal of poka-yoke is both prevention and detection: "errors will not turn into defects if feedback and action take place at the error stage." (Shigeo Shingo, industrial engineer at Toyota. He is credited with starting "Zero Quality Control"). The best operation is one that both produces and inspects at the same time. Figure 3 shows a Poka-Yoke device which prevents a floppy disk from being put in the wrong way into the computer.

There are three approaches to Poka-Yoke:

- Warning (let the user know that there is a potential problem – like door ajar warning in a car)
- Control (automatically change the process if there is a problem – like turn on windshield wipers in case of rain in some advanced cars)
- Shutdown (close down the process so it does not cause damage – like deny access to ATM machines if password entered is wrong 3 times in a row)

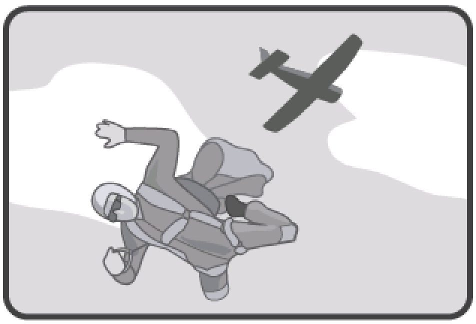


Figure 3: Poka-Yoke Example – the possibility of parachute not opening needs to be eliminated

2.4 What are 7 Wastes in Lean?

The 7 Wastes (also referred to as Muda) in Lean are:

- Overproduction
- Correction (defects, rework)
- Inventory
- Motion
- Over-processing
- Transportation
- Waiting

The underutilization of talent and skills is sometimes called the **8th waste in Lean.**

Waste 1: Overproduction is producing more than the next step needs or more than the customer buys. Waste of Overproduction relates to the excessive accumulation of work-in-process (WIP) or finished goods inventory. It may be the worst form of waste because it contributes to all the others. Examples are:

- Preparing extra reports
- Reports not acted upon or even read
- Multiple copies in data storage
- Over-ordering materials

Waste 2: Correction or defects are as obvious as they sound. Waste of Correction includes the waste of handling and fixing mistakes. This is common in both manufacturing and transactional settings. Examples are:

- Incorrect data entry
- Paying the wrong vendor
- Misspelled words in communications
- Making bad product or materials or labour discarded during production

Waste 3: Inventory is the liability of materials that are bought, invested in and not immediately sold or used. Waste of Inventory is identical to overproduction except that it refers to the waste of acquiring raw material before the exact moment that it is needed. Examples are:

- Transactions not processed
- Bigger “in box” than “out box”
- Over-stocking raw materials

Waste 4: Motion is the unnecessary movement of people and equipment. This includes looking for things like documents or parts as well as movement that is straining. Waste of Motion examines how people move to ensure that value is added. Examples are:

- Extra steps
- Extra data entry
- Having to search for something for approval

Waste 5: Over processing is tasks, activities and materials that don’t add value. Can be caused by poor product or process design as well as from not understanding what the customer wants. Waste of Over-processing relates to over-processing anything that may not be adding value in the eyes of the customer. Examples are:

- Sign-offs
- Reports that contain more information than the customer wants or needs
- Communications, reports, emails, contracts, etc that contain more than the necessary points (concise is better)
- Voice mails that are too long
- Duplication of effort/reports

Waste 6: Transportation is the unnecessary movement of material and information. Steps in a process should be located close to each other so movement is minimized. Examples are:

- Extra steps in the process
- Distance travelled
- Moving paper from place to place

- Forwarding emails to one another

Waste 7: Waiting is non-productive time due to lack of material, people, or equipment. This can be due to slow or broken machines, material not arriving on time, etc. Waste of Waiting is the cost of an idle resource. Examples are:

- Processing once each month instead of as the work comes in
- Waiting on part of customer or employee for a service input
- Delayed work due to lack of communication from another internal group

3 DMAIC Overview - D Phase

3.1 Objectives of Define Phase

To identify and/or validate the improvement opportunity, develop the business processes, define critical customer requirements, and prepare to be an effective project team.

Main Activities:

- Validate/Identify Business Opportunity
- Validate/Develop Team Charter
- Identify and Map Processes
- Identify Quick Wins and Refine Process
- Translate Voice of the Customer (VOC) into Critical Customer Requirements (CCRs)
- Develop Team Guidelines & Ground Rules

Key Deliverables:

- Team Charter (includes Action Plan)
- High Level Process Maps
- Prepared Team

3.2 Project Charter

A project charter is a written document and works as an agreement between management and the team about what is expected. The charter clarifies what is expected of the team and keeps the team focussed and aligned on the organizational priorities. It transfers the project from the champion to the project team. Elements of a Project Charter:

- Opportunity Statement: Pain or Problems
- Business Case: Purpose from Benefits Perspective
- Goal Statement: Success Criteria
- Project Scope: Boundaries
- Project Plan: Activities
- Team Selection: Who and What

Opportunity Statement: The opportunity statement describes the “why” of undertaking the improvement initiative. The problem statement should address the following questions:

- What is wrong or not working?
- When and where do the problems occur?
- How extensive is the problem?
- What is the impact "pain" on our customers / business / employees?

Business Case: The business case describes the benefit for undertaking a project. The business case addresses the following questions:

- What is the focus for the project team?
- Does it make strategic sense to do this project?
- Does this project align with other business initiatives (Critical Success Factors)?
- What benefits will be derived from this project?
- What impacts will this project have on other business units and employees?

Goal Statement: The goal statement should be most closely linked with the Opportunity statement. The goal statement defines the objective of the project to address the specific pain area, and is SMART (Specific, Measurable, Attainable, Relevant and Time-bound). The goal statement addresses:

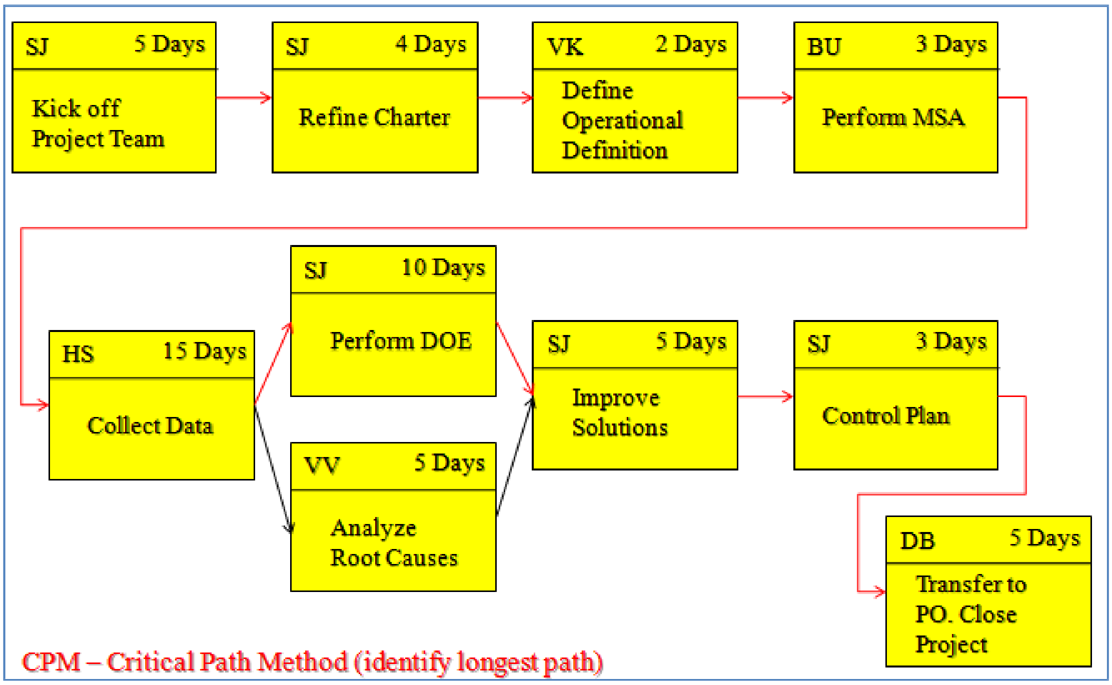
- What is the improvement team seeking to accomplish?
- How will the improvement team's success be measured?
- What specific parameters will be measured? These must be related to the Critical to Cost, Quality, and/or Delivery (Collectively called the CTQ's).
- What are the tangible results deliverables (e.g., reduce cost, cycle time, etc.)?
- What is the timetable for delivery of results?

Project Scope: The project scope defines the boundaries of the business opportunity. One of the Six Sigma tools that can be used to identify/control project scope is called the In-Scope/Out-of-Scope Tool. Project Scope defines:

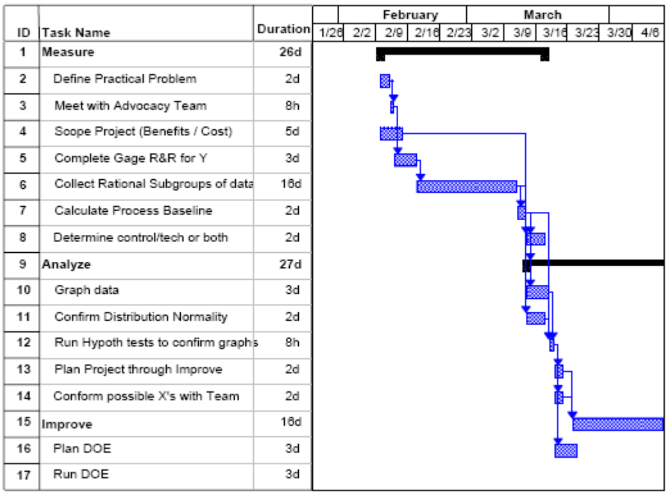
- What are the boundaries, the starting and ending steps of a process, of the initiative?
- What parts of the business are included?
- What parts of the business are not included?
- What, if anything, is outside the team's boundaries?
- Where should the team's work begin and end?

Project Plan: The project plan shows the timeline for the various activities required for the project. Some of the tools that can be used to create the project timeline are the Network diagram (or PERT chart), the GANTT chart etc.

A Network diagram (or PERT chart) helps with identification of the critical path which is the longest path in the process. Any activities that get delayed on the critical path directly affect the end point of the project. In the example below, the element "Analyze Root Cause" is not on the critical path because its duration is less than a parallel activity that takes longer. So, for items that are not on the critical path, small delays will not necessarily affect the project completion date. The Critical Path Method (CPM) calculates the longest path in a project so that the project manager can focus on the activities that are on the critical path and get them completed on time.



A GANTT chart shows a summary of the project plan. It has task details, resource details, durations, and expected start and stop dates for the project. A GANTT chart can also show % completed activities (not shown in figure below). It is a good visual indicator of the project plan.



3.3 Team Roles & Responsibilities

Yellow Belt:

- Provide support to Black Belts and Green Belts as needed
- May be team members on DMAIC teams
- Supporting projects with process knowledge and data collection

Green Belt:

- Is the Team Leader for a Project within own functional area
- Selects other members of his project team
- Defines the goal of project with Champion & team members
- Defines the roles and responsibilities for each team member
- Identifies training requirements for team along with Black Belt
- Helps make the Financial Score Card along with his CFO

Black Belt:

- Leads project that are cross-functional in nature (across functional[2] areas)
- Ends role as project leader at the close of the turnover meeting
- Trains others in Six Sigma methodologies & concepts

[2] Cross functional projects are more complex to manage as it involves several people from different departments. This will require significant change management effort, if not managed well could take a lot longer than expected & there are greater chances for failure.

- Sits along with the Business Unit Head and helps project selection
- Provides application assistance & facilitates team discussions
- Helps review projects with Business Unit Head
- Informs Business Unit Head of project status for corrective action

Master Black Belt:

- Participates in the Reviews and ensures proper direction.
- Teaches and coaches Process Owners on Process Management principles

Team Member:

- A Team Member is chosen for a special skill or competence
- Team Members help design the new process
- Team Members drive the project to completion

Subject Matter Expert (SME):

- Is an expert in a specific functional area
- May be invited to specific team meetings but necessarily all of them
- Provides guidance needed to project teams on an as-needed basis

Project Sponsor:

- Acts as surrogate Process Owner (PO) until an owner is named
- Becomes PO at Improve/Develop if PO is not named
- Updates Tracker with relevant documents and pertinent project data
- Part of senior management responsible for selection / approval of projects

Process Owner:

- Takes over the project after completion
- Manages the control system after turnover
- Turns over PO accountability to the new Process Owner if the process is reassigned to another area or another individual

Deployment Champion:

- Responsible for the overall Six Sigma program within the company

- Reviews projects periodically
- Adds value in project reviews since he is hands-on in the business
- Clears road blocks for the team
- Has the overall responsibility for the project closure

3.4 Team Tools

Brainstorming is an effective way to generate lots of ideas (potential solutions) on a specific issue and then determine which idea – or ideas – is the best solution. Brainstorming is most effective with groups of 8-12 people and should be performed in a relaxed environment. If participants feel free to relax and joke around, they'll stretch their minds further and therefore produce more creative ideas.

A brainstorming session requires a facilitator, a brainstorming space and something on which to write ideas, such as a white-board a flip chart or software tool. The facilitator's responsibilities include guiding the session, encouraging participation and writing ideas down. Brainstorming works best with a varied group of people. Participants should come from various departments across the organisation and have different backgrounds. Even in specialist areas, outsiders can bring fresh ideas that can inspire the experts.
There are numerous approaches to brainstorming, but the traditional approach is generally the most effective because it is the most energetic and openly collaborative, allowing participants to build on each others' ideas.

Multi-voting is a mechanism to narrow down the list of ideas and select the right subset for further investigation. Each team members is given a certain number of votes which he places on the ideas that he/she supports with minimal discussion. At the end of the voting by all team members, the ideas which have the highest number of votes is selected for further study. This process may be repeated to further narrow down the list. Table 2 shows voting results for six different ideas. Based on the votes, ideas 1 and 6 were selected for deployment.

Item	**Number of Votes**
1. Have a meeting agenda	● ● ● ● ●
~~**2. Inform participants why they have to attend meeting**~~	● ●
~~**3. Have someone take notes at the meeting**~~	●
~~**4. Have a clear meeting objective**~~	● ● ●
~~**5. Reduce the number of topics to be discussed at each meeting**~~	●
6. Start and end meetings on time	● ● ● ● ● ●

Table 2: Multi-Voting Example

Nominal Group Technique: A technique that supplements brainstorming. Structured approaches to generate additional ideas, surveys the opinions of a small group, and prioritize brainstormed ideas. The nominal group technique is a decision making method for use among groups who want to make their decision quickly, as by a vote, but want everyone's opinions taken into account. First, every member of the group gives their view of the solution, with a short explanation. Then, duplicate solutions are eliminated from the list of all solutions, and the members proceed to rank the solutions, 1st, 2nd, 3rd, 4th, and so on. The numbers each solution receives are totalled, and the solution with the lowest (i.e. most favoured) total ranking is selected as the final decision. Figure 4 shows results of the nominal group technique. Each idea was ranked by several team members. The idea with the lowest total score is selected as the winner. In this example (Idea N).

- Structured to focus on problems, not people. To open lines of communication, tolerate conflicting ideas.
- Builds consensus and commitment to the final result. Especially good for highly controversial issues
- Nominal Group Technique is most often used after a brainstorming session to help organize and prioritize ideas

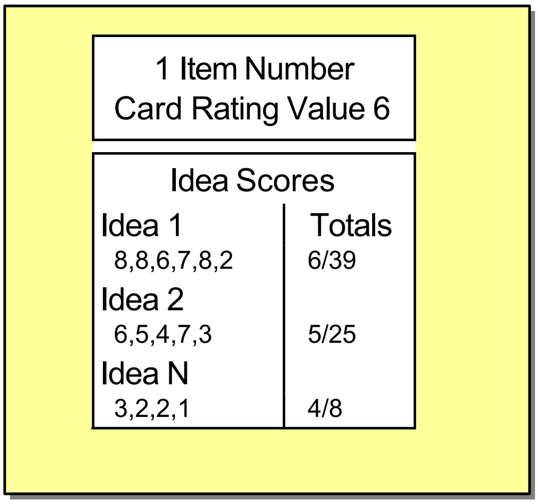


Figure 4: Example of Nominal Group Technique with Ideas Rated

Delphi Technique: It is a method of relying on a panel of experts to anonymously select their responses using a secret ballot process. After each round, a facilitator provides the summary of the experts' opinions along with the reasons for their decisions. Participants are encouraged to revise their answers in light of replies from other experts. The process is stopped after pre-defined criteria such as number of rounds. The advantage of this technique is that if there are team members who are boisterous or overbearing, they will not have much of an impact on swaying the decisions of other team members.

4 DMAIC Overview - M Phase

4.1 Objectives of Measure Phase

To identify critical measures that are necessary to evaluate the success meeting critical customer requirements and begin developing a methodology to effectively collect data to measure process performance. To establish baseline sigma for the processes the team is analyzing.

Main Activities:

- Identify Input, Process, and Output Indicators
- Develop Operational Definition & Measurement Plan
- Plot and Analyze Data
- Determine if Special Cause Exists
- Determine Sigma Performance
- Collect Other Baseline Performance Data

Key Deliverable:

- Reliable assessment of current performance

4.2 Process Maps

Process maps are graphical representations of a process flow identifying the steps of the process, the inputs and outputs of the process, and opportunities for improvement. Process maps can cross functional boundaries if the start points and stop points are located in different departments or if several persons from different departments are responsible for satisfied the specific customer need. Process maps are applicable to any type of process: manufacturing, design, service, or administrative. Process maps are used to document the actual process and located value and non-value added steps. These maps can be an excellent way to communicate information to others and train employees. Process Maps can be used to document non-value added steps (anything that the customers are not willing to pay for). Identification of non-value added steps paves the way to get rid of these steps in future phases of DMAIC.

The initial AS-IS process maps should always be created by cross functional team members and must reflect the actual process rather than an ideal state of desired state.

SIPOC is an acronym for Suppliers – Inputs – Process – Outputs – Customers. It is a high level process map that describes the boundaries of the process, major tasks and activities, Key Process Input and Output Variables, Suppliers & Customers. When we refer to customers, we usually talk about both internal and external customers. It can be used to identify the key stakeholders and describe the process visually to team members and other stakeholders. A stakeholder is anyone who is either impacted by the project or could impact the outcome of the project. Not everyone is a stakeholder but a project may have several stakeholders including employees, suppliers, customers, shareholders etc. Figure 5 shows a filled out SIPOC matrix.

Suppliers: Provide inputs

Inputs: Data / unit required to execute the process

Process Boundary: Identified by the hand-off at the input (the start point of process) and the output (the end point of the process)

Outputs: Output of a process creating a product or service that meets a customer need

Customers: Users of the output

Suppliers (Providers of the required resources)	Inputs (Resources required by the process)	Process (Top level description of activity)		Outputs (Deliverables from the process)	Customers (Anyone who receives a deliverable from the process)	
		Requirements			Requirements	
Client	Request for Travel	Dates		Service	Professional and Courteous	Business/ Corporate Traveler
Company	Company Travel Authorization	Travel Approval Code	Customer Request For Travel	Time to Process	Less Than 10 Minutes	Business/ Corporate Traveler
Traveler	Availability	Initiates Reservation		Cost	Low to Moderate Cost	Biggest Client
Company Travel Agency	Request For Reservation	Company Profile, Traveler Profile, Author. Code	Booking a Business Airline Reservation	Carrying Cost	Low to Moderate Cost	Company
Traveler	Travel Information	Departure and Arrival Cities, Date, Times		Travel Itinerary	Mail/email, carrier, times, dates, seat, special requests	Business/ Corporate Traveler
Traveler	Payment Method	Current Credit Card w/available credit limit	Airline Reservation	Ticket or E-ticket	Zero Defects	Business/ Corporate Traveler
Traveler	Address; mail and/or email	Correct		Revenue	Profit Margin	Travel Agent and Carrier
				Billings	Electronic Communication Daily	Company Acct Rec, Credit Card Company

Figure 5: SIPOC Example

Top-Down Flow Chart is a flow chart that describes the process using the symbols shown in the following table.

	Start & End Points	Identify the boundaries of the process.
	Activity	What is being done. Indicates necessary and unnecessary activities performed in the process.
	Decision	Illustrates decision points and where loops occur in the process. Also used to accept, reject, approve, etc.
	Arrow	Represents a process path/flow.
	Input or Output	Shows important inputs or outputs without describing in detail.
	Process Connectors	Connect flow to another page or process.
A#	**Activity Number**	Shows the activity in the sequence performed.
D#	**Decision Number**	Shows the decision points in the sequence performed.

*Table **3: Typical Symbols used in Process Maps***

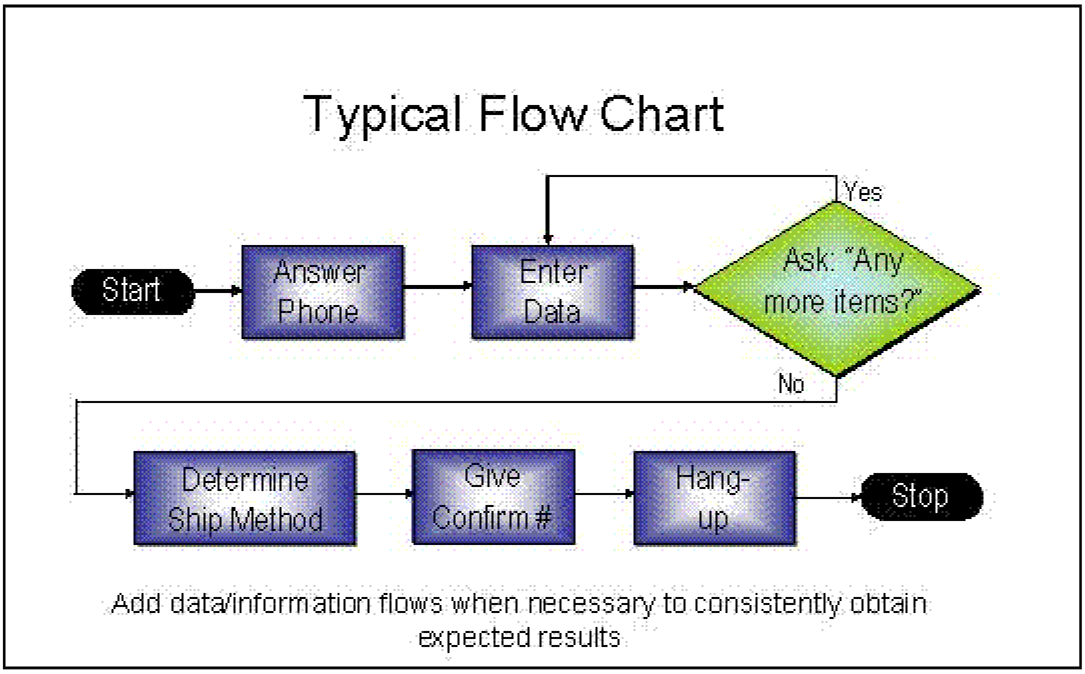


Figure 6: Typical Flow Chart

Functional Deployment Flow Chart: A functional deployment flow chart shows the different functions that are responsible for each step in the process flow chart. An example is shown below:

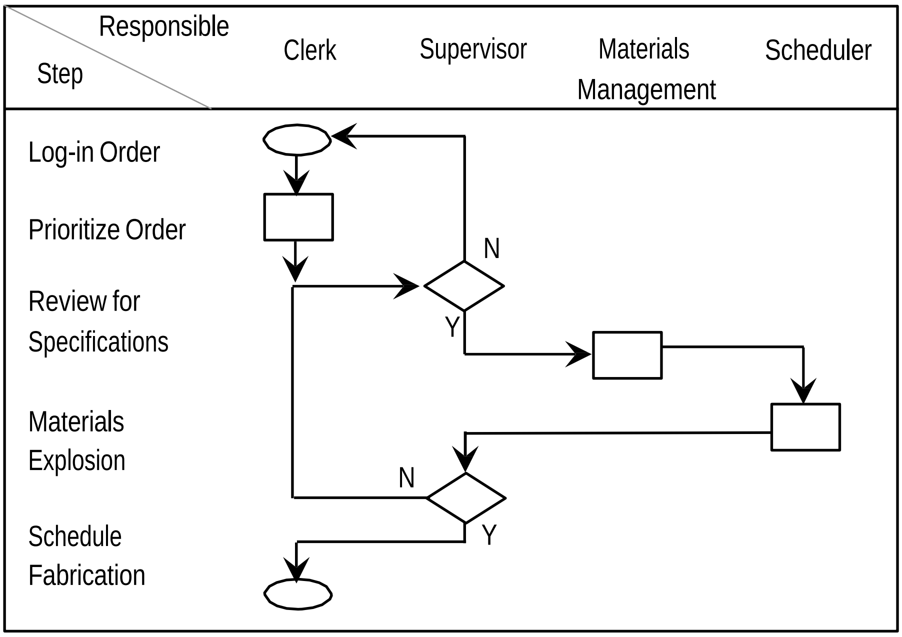


Figure 7: Example Process Maps with Functions Shown

4.3 *Data Collection & Summarization*

Before data collections starts, classify the data into different types: continuous or discrete. Figure 8 shows examples of different types of continuous and attribute data.

Continuous or variable		**Discrete, categorical, or attribute**	
Measured on a continuum		**Count or Categories**	
Objective	**Subjective**	**Objective**	**Subjective**
• Time • Money • Weight • Length	• Satisfaction • Agreement • Extent	• Count defects • # approved • # of errors • Type of document	• Yes/No • Categories • Service performance rating (good, poor)

Figure 8: Different Types of Data

Sometimes it is very costly or time consuming to collect all the data that is available. In these cases, we resort to sampling. Sampling refers to collecting only a subset of the data and still be able to make good decisions from this subset of data instead of having the collect the data for the entire population.

- Is the sample representative of the process or population?
- Is the process stable?
- Is the sample random?
- Is there an equal probability of selecting any data point within a homogenous group?
- The answer to each of these questions must be yes before we can draw statistically valid conclusions.

Three common types of Sampling are: Random Sampling (samples to be selected cannot be predicted), Stratified Sampling (make sure that we sample each of the different segments), and systematic sampling (every 100th piece)

In **random sampling**, all items have some chance of selection that can be calculated. Random sampling technique ensures that *bias* is not introduced regarding who is included in the survey. For example, each name in a telephone book could be numbered sequentially. If the sample size was to include 2,000 people, then 2,000 numbers could be randomly generated by computer or numbers could be picked out of a hat. These numbers could then be matched to names in the telephone book, thereby providing a list of 2,000 people.

Systematic sampling, sometimes called interval sampling, means that there is a gap, or interval, between each selection. This method is often used in industry, where an item is selected for testing from a production line (say, every fifteen minutes) to ensure that machines and equipment are working to specification. This technique could also be used when questioning people in a sample survey. A market researcher might select every 10th person who enters a particular store, after selecting a person at random as a starting point; or interview occupants of every 5th house in a street, after selecting a house at random as a starting point.

A general problem with random sampling is that you could, by chance, miss out a particular group in the sample. However, if you form the population into groups, and sample from each group, you can make sure the sample is representative. In **stratified sampling**, the population is divided into groups called strata. A sample is then drawn from within these strata. Some examples of strata commonly used in Census studies are States, Age and Sex. Other strata may be religion, academic ability or marital status. For example, if a particular subgroup is 10% of the entire population and we want to sample 100 points overall, we would randomly pick 10 points from this subgroup.

<u>TOOLS for Data Collections</u>

Check Sheets: Are probably the most common type of data collection forms used, but there are a variety of other data collection forms. Simple data collection form that helps determines how often something occurs. Figure 9 shows an example check list. These are beneficial for use in real time as they are very easy to understand and use.

Concentration Diagrams: Are most commonly physical representations of a product that has marks on it to show what problems occurred and where on the product they occurred. However, an example shown later in this module shows how the same idea can be applied to an administrative form. In this case, the object on which errors were occurring was the form that employees were filling out. By using a concentration diagram, the company can see what errors are being made and where on the object the errors occur most frequently. Figure 10 shows a concentration diagram which shows that most errors occur in the upper left hand corner of the Printed Circuit Board.

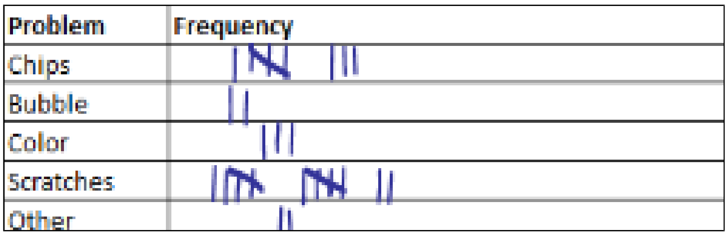


Figure 9: Check Sheet Example

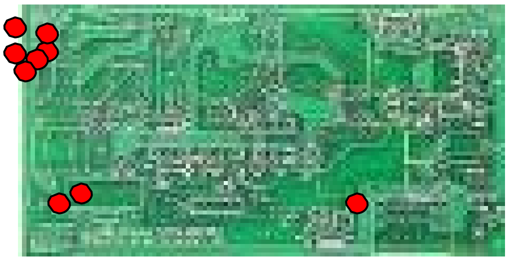


Figure 10: Concentration Diagram showing location of Defects

Pareto Charts is a type of bar graph used to arrange information in such a way that it can be used to prioritize process improvements. The chart is similar to the histogram or bar chart, except that the bars are arranged in decreasing order from left to right along the abscissa. The fundamental idea behind the use of Pareto diagrams for quality improvement is that the first few (as presented on the diagram) contributing causes to a problem usually account for the majority of the result. Pareto charts are sometimes referred to as identifying the vital few from the trivial many. Targeting these "major causes" results in the most cost-effective improvement scheme. The Pareto example in Figure 11 shows that Caulking and Connecting are the biggest sources of the problem accounting for 60% of the total problem.

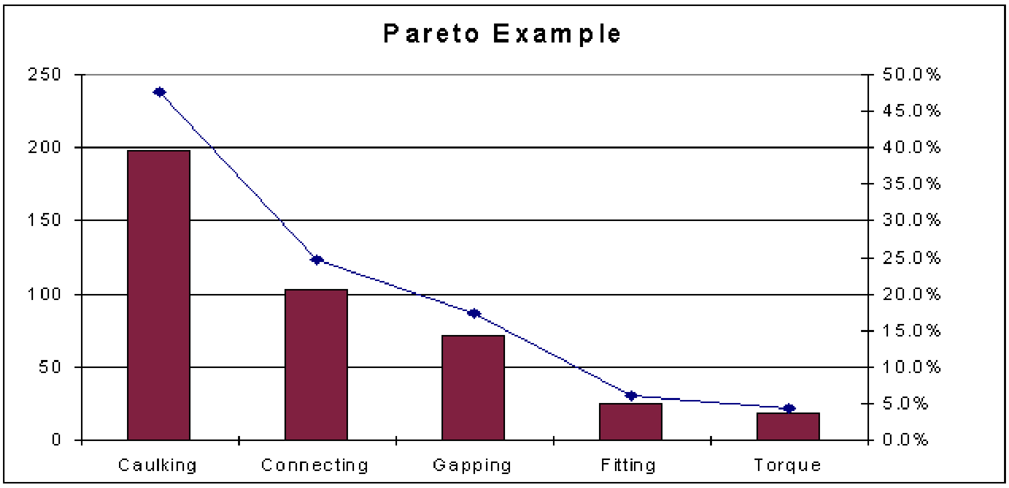


Figure 11: Pareto Example

Histograms are charts that show the frequency of occurrence of values. Figure 12 shows an example histogram. For example, if we do a customer survey and there are 10 choices in the survey, a histogram can be used to plot how many respondents picked option 1, how many picked option 2, and so on. Histograms are good ways to show summary of data values. In this example, most respondents chose option 6 with the lowest option being Option 3 and the highest being Option 9.

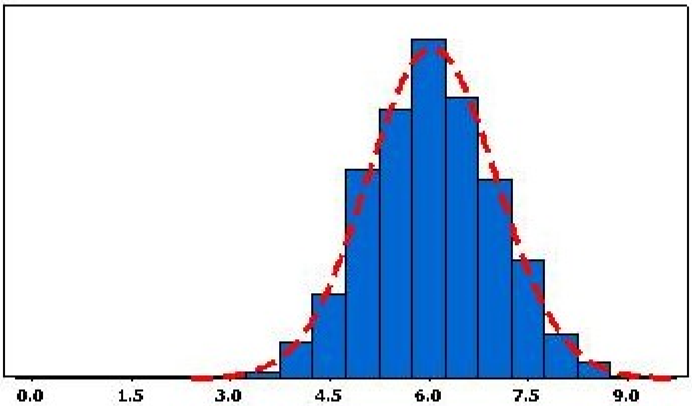


Figure 12: Histogram Example (Customer Survey Results)

5 DMAIC Overview - A Phase

5.1 Objectives of the Analyze Phase

To stratify and analyze the opportunity to identify and validate the "real" root causes of the problem.

Main Activities:

- Stratify Process
- Stratify Data & Identify Specific Problem
- Develop Problem Statement
- Identify Root Causes
- Design Root Cause Verification Analysis
- Validate Root Causes
- Enhance Team Creativity & Prevent Group-Think

Key Deliverable:

- Validated Root Causes

5.2 Generation of Potential Solutions

Cause & Effect or Fishbone Diagram: A graphic tool used to explore and display opinion about sources of variation in a process. The purpose is to arrive at a few key sources that contribute most significantly to the problem being examined. These sources are then targeted for improvement. The diagram also illustrates the relationships among the wide variety of possible contributors to the effect. The figure below shows a simple Ishikawa diagram. Note that this tool is referred to by several different names: Ishikawa diagram, Cause-and-Effect diagram, Fishbone diagram, and Root Cause Analysis. The first name is after the inventor of the tool, Kaoru Ishikawa (1969) who first used the technique in the 1960s. The basic concept in the Cause-and-Effect diagram is that the name of a basic problem of interest is entered at the right of the diagram at the end of the main "bone". The main possible causes of the problem (the effect) are drawn as bones off of the main backbone. This tool can be used to brainstorm for potential causes and then narrow down the causes to be investigated further. Figure 13 shows a partially filled out fishbone diagram.

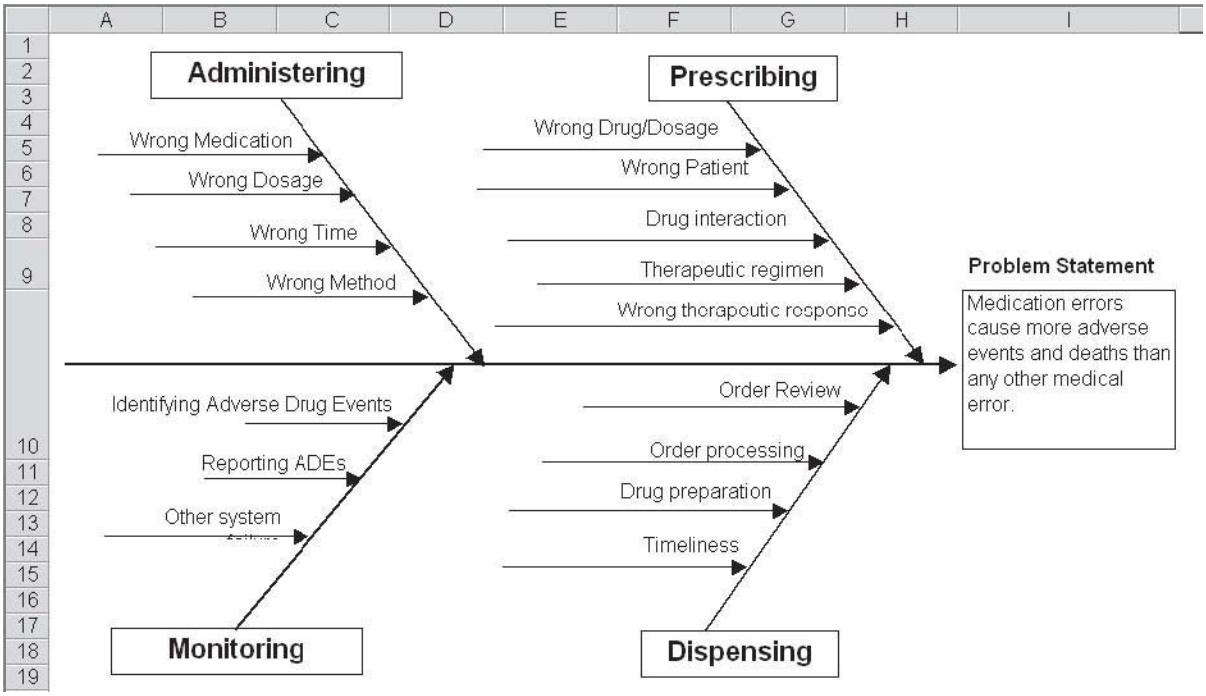


Figure 13: Fishbone Diagram Example

Five Why's Analysis: Asking "Why?" may be a favourite technique of your three year old child in driving you crazy, but it could teach you a valuable Six Sigma quality lesson. The 5 Whys is a technique used in the Analyze phase of the Six Sigma DMAIC methodology. By repeatedly asking the question "Why" (five is a good rule of thumb), you can peel away the layers of symptoms **which can lead to the root cause of a problem**. Although this technique is called "5 Whys," you may find that you will need to ask the question fewer or more times than five before you find the issue related to a problem. The benefits of 5 Why's is that it is a simple tool that can be completed without statistical analysis. Table 4 shows an illustration of the 5 Why's analysis. Based on this analysis, we may decide to take out the non-value added signature for the director.

	Customers are unhappy because they are being shipped products that don't meet their specifications.
Why	Because manufacturing built the products to a specification that is different from what the customer and the sales person agreed to.
Why	Because the sales person expedites work on the shop floor by calling the head of manufacturing directly to begin work. An error happened when the specifications were being communicated or written down.
Why	Because the "start work" form requires the sales director's approval before work can begin and slows the manufacturing process (or stops it when the director is out of the office).
Why	Because the sales director needs to be continually updated on sales for discussions with the CEO.

Table 4: 5 Why's Example

6 DMAIC Overview - I Phase

6.1 Objectives of the Improve Phase

To identify, evaluate, and select the right improvement solutions. To develop a change management approach to assist the organization in adapting to the changes introduced through solution implementation.

Main Activities:

- Generate Solution Ideas
- Determine Solution Impacts: Benefits
- Evaluate and Select Solutions
- Develop Process Maps & High Level Plan
- Communicate Solutions to all Stakeholders

Key Deliverables:

- Solutions
- Process Maps and Documentation

6.2 Solution Selection

Pugh Matrix refers to a matrix that helps determine a solution from a list of potential solutions. It is a scoring matrix used for concept selection, in which options are assigned scores relative to some pre-defined criteria. The selection is made based on the consolidated score. The Pugh matrix is a tool to facilitate a methodical team based approach for the selection of the best solution. It combines the strengths of different solutions and eliminates the weaknesses. This solution then becomes the datum of the base solution against which other solutions are compared. The process is iterated until the best solution or concept emerges. Figure 14 shows an example of Pugh matrix. From this example, we can conclude that options B, C, and D have more number of negatives compared to option A. Hence, we would pick option A as the best solution.

When the root causes and solutions are selected, we need to ensure that the project team has demonstrated that the primary metric is better than the goal established for the project.

Evaluation Criteria	Imp	A	B	C	D
Ease of guests finding the lobby for check-in	3	S	S	S	-
Minimum weight times for the check-in process	5	S	-	-	+
Minimum errors in room assignment	5	S	-	S	S
Appearance of the lobby area – cleanliness	4	S	-	-	-
Sum of Same		4	1	2	1
Sum of Positives		0	0	0	1
Sum of Negatives		0	3	2	2
Weighted Sum of Positives		0	0	0	5
Weighted Sum of Negatives		0	14	9	7

Figure 14: Example Pugh Matrix

6.3 John Kotter's 8 Step Change Management Plan

According to John Kotter, the following eight steps have to be followed to enable change within an organization. One of the most common reasons for project failure is lack of communication.

- Step 1: Increase Urgency
- Step 2: Build a Guiding Team
- Step 3: Get the Vision Right
- Step 4: Communicate for Buy-In
- Step 5: Empower Action
- Step 6: Create Short-Term Wins
- Step 7: Don't Let Up
- Step 8: Make Change Stick

6.4 Change Management Issues

We will discuss three change management tools: Force Field analysis, Stakeholder analysis, and Resistance analysis.

Force Field Analysis is a useful technique for looking at all the forces for and against a decision. It helps in identifying the restrainers and drivers to change. In effect, it is a specialized method of weighing pros and cons. By carrying out the analysis you can plan to strengthen the forces supporting a decision, and reduce the impact of opposition to it. Figure 15 shows an example Force Field analysis. In this example, there are 4 forces for the change and 2 forces against the change. This indicates that there are more forces for the change. Can you think of deploying some action items to further increase the forces for change?

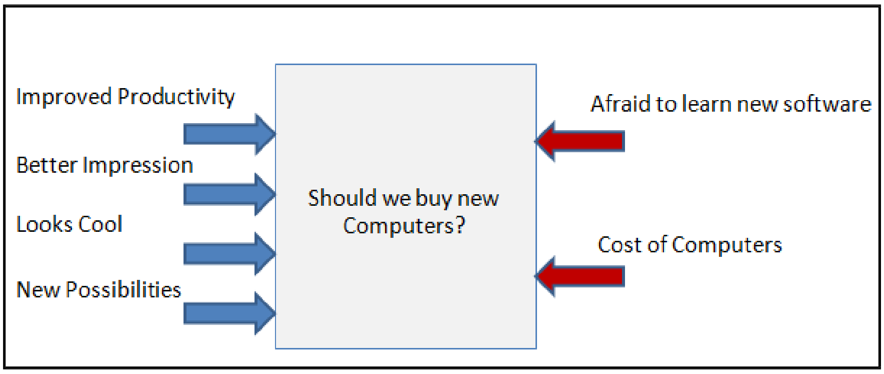


Figure 15: Sample Force Field Analysis

Stakeholder Analysis is a technique that identifies individuals or groups affected by and capable of influencing the change process. Assessment of stakeholders and stakeholder issues and viewpoints are necessary to identify the range of interests that need to be taken into consideration in planning change and to develop the vision and change process in a way that generates the greatest support. The following parameters are used to develop the segmentation of the stakeholders:

- Levels of Influence: *High, Medium, Low*
- Level of Impact: *High, Medium, Low*
- Minimum Support Required: *Champion, Supporter, Neutral*
- Current Position: *Champion, Supporter, Neutral, Concerned, Critic, Unknown*

<u>Stakeholder Action Plan:</u>

1. The plan should outline the perceptions and positions of each stakeholder group, including means of involving them in the change process and securing their commitment
2. Define how you intend to leverage the positive attitudes of enthusiastic stakeholders and those who "own" resources supportive of change
3. State how you plan to minimize risks, including the negative impact of those who will oppose the change
4. Clearly communicate coming change actions, their benefits and desired stakeholder roles during the change process
5. Maintained on an ongoing basis

Resistance Analysis

- **Technical Resistance:** stakeholders believe 6 Sigma produces feelings of inadequacy or stupidity on statistical and process knowledge
- **Political Resistance:** stakeholders see 6 Sigma as a loss of power and control
- **Organizational Resistance:** stakeholders experience issues of pride, ego and loss of ownership of change initiatives
- **Individual Resistance:** stakeholders experience fear and emotional paralysis as a result of high stress

Strategies to Overcome Resistance:

- **Technical Resistance:** focus on high-level concepts to build competencies. Then add more statistical theorems as knowledge base broadens
- **Political Resistance:** address issues of "perceived loss" straight on. Look for champions to build consensus for 6 Sigma and its impact on change
- **Organizational Resistance:** look for ways to reduce resistance.
- **Individual Resistance:** decrease the fear by increased involvement, information and education

6.5 *Stages of a Team*

The four stages that all teams go through are shown below. In each phase, the project leader has to user different techniques to push the team along.

➢ **Form**

- Identifying and informing members
- Everyone is excited at the new responsibilities
- Use Project Charter to establish a common set of expectations for all team members

➢ **Storm**

- Teams start to become disillusioned. Why are we here, is the goal achievable?
- Identifying resistors, counselling to reduce resistance.
- Help people with the new roles & responsibilities
- Have a different person take meeting minutes, lead team meetings etc

➢ **Norm**

- Informing norms (rules), building up of relationships amongst members.
- Productivity of team is increasing
- Help team push to the next stage

➢ **Perform**

- Contribution from the members- Ideas, innovation, creation.
- All members contribute to the fullest.
- Teams should reach this stage quickest for the best results.
- Motivate team members by recognition, financial rewards, quick-win opportunities.

Some of the problems with teams are:

- Groupthink – which is the unquestioned acceptance of teams' decisions
- Feuding – fighting between different team members
- Floundering – teams that take forever to reach a decision
- Rushing – teams that want to skip all steps and finish the project soon

7 DMAIC Overview - C Phase

7.1 Objectives of the Control Phase

To ensure process control over the long term, disseminate lessons learned, identify replication and standardization opportunities/processes, and develop related plans.

Main Activities:

- Develop and Implement Pilot Plan and Solution
- Verify Reduction in Root Cause Sigma Improvement Resulted from Solution
- Identify if Additional Solutions are Necessary to Achieve Goal
- Identify and Develop Replication & Standardization Opportunities
- Integrate and Manage Solutions in Daily Work Processes
- Integrate Lessons Learned
- Identify Teams Next Steps & Plans for Remaining Opportunities

Key Deliverables:

- Process Control Plan

7.2 Tools to Sustain Improvements

Control Plan: It is a document that helps with ensuring long term control of the process.

Process Description

- Reflects a key process, job or group of work tasks
- Uses simple and general terms
- Must be understandable for owners, customers, and users

Process Purpose

- Describes the desired process outcome
- Must be measurable (must be measurable as a set of customer driven specifications)

Quality/Outcome Indicator

- Measures how well the Customer requirements/process purpose is being met

Process Map

- The set of sequential and parallel activities that must be completed to ensure the Customer requirement /process purpose is met
- Shows individual as well as cross-functional accountability

Indicators

- A set of indicators identified after the process is developed that measure compliance of critical process activities to process specifications
- Must be tied to the specific process activities
- Must provide upstream indication of the quality of the outcome of the process

Control Limits & Specifications

- The specification limits or targets that define acceptable levels of quality performance for the quality and process indicators

Checking

- Defines the specific items to be checked
- Defines the frequency at which they should be checked
- Defines the individual accountable for checking

Actions

- Defines the contingency actions that should be taken in response to certain identified events

Miscellaneous Information

- Must include references to standards and procedures
- Should identify all procedures and standards required to perform the activities specified on the process map
- Standards and Procedures
    - Each procedure must define the specific set of instructions necessary to perform an identified activity
    - Standards and procedures must conform to a standardized *form and format*
    - *Form and format* should simplify execution of the activities and reduce the possibility of miscommunication and mistakes

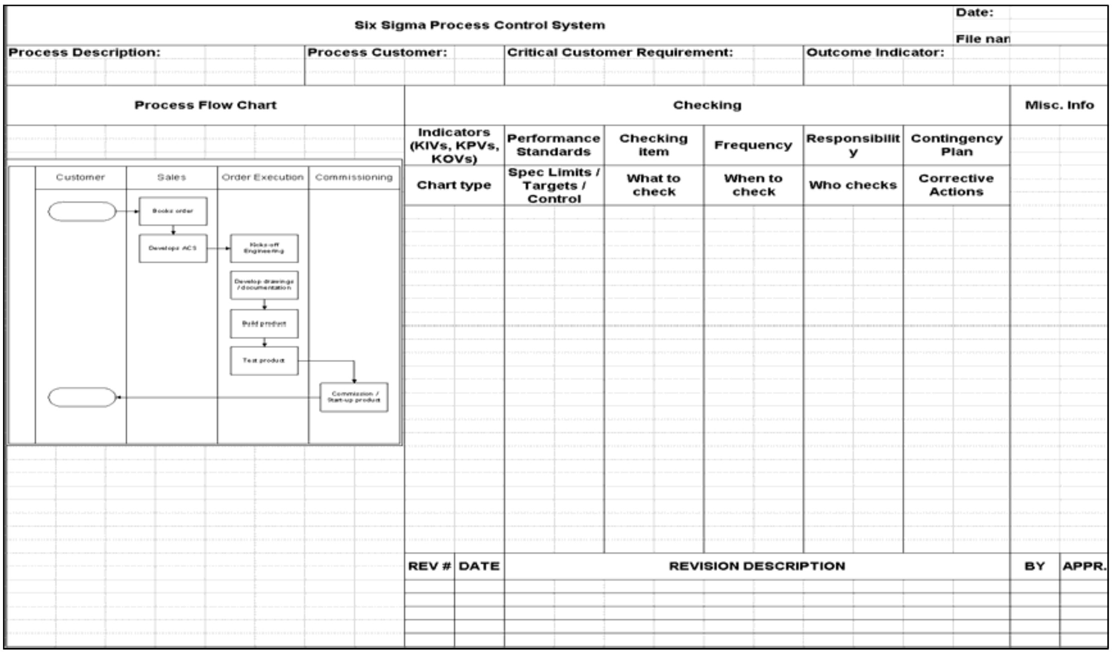


Figure 16: Control Plan Example

<u>Control Charts</u>

Control charts have the ability to indicate the presence of special causes that upset processes. Note that control charts are not there to detect if a process is performing to specifications or not. It helps to detect, diagnose, and correct process problems in a timely fashion. It provides an easy to understand visual indicator of process performance and recognize the extent of variation that now exists so that we do not overreact to common cause variation (tweaking). Figure 17 shows two control charts. The first control chart has all data points within the control limits (LC and UC), hence this plot is in control. The second chart has some data points that fall outside the control limits, hence this plot is out of control.

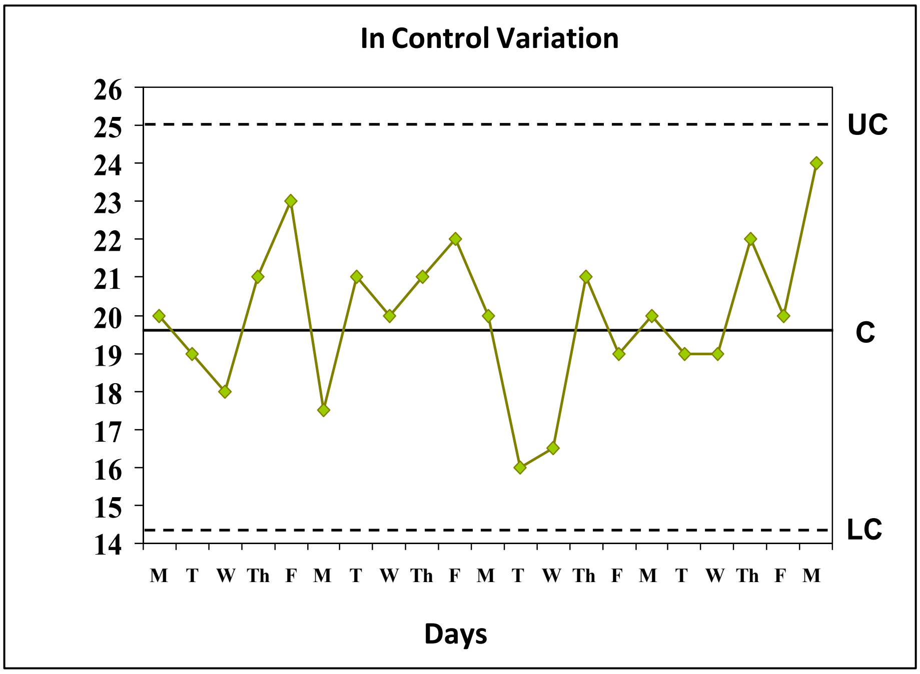
There are two types of variations: Common cause and Special cause.

Common Cause:

- There are always inherent chance causes responsible for natural variation in all processes due to “normal” variation in materials, environments, methods, etc. (common cause)
- Variation within a stable pattern of chance causes is inevitable

Special Cause:

- Once we have an indication of a shift outside a stable pattern of variation, we must discover the reason for the shift (special cause)
- We want to remove the influence of a special cause if it is adversely affecting product-process quality
- If the special cause influence is improving product-process quality (e.g., 6 Sigma projects), we want to permanently capture its effect



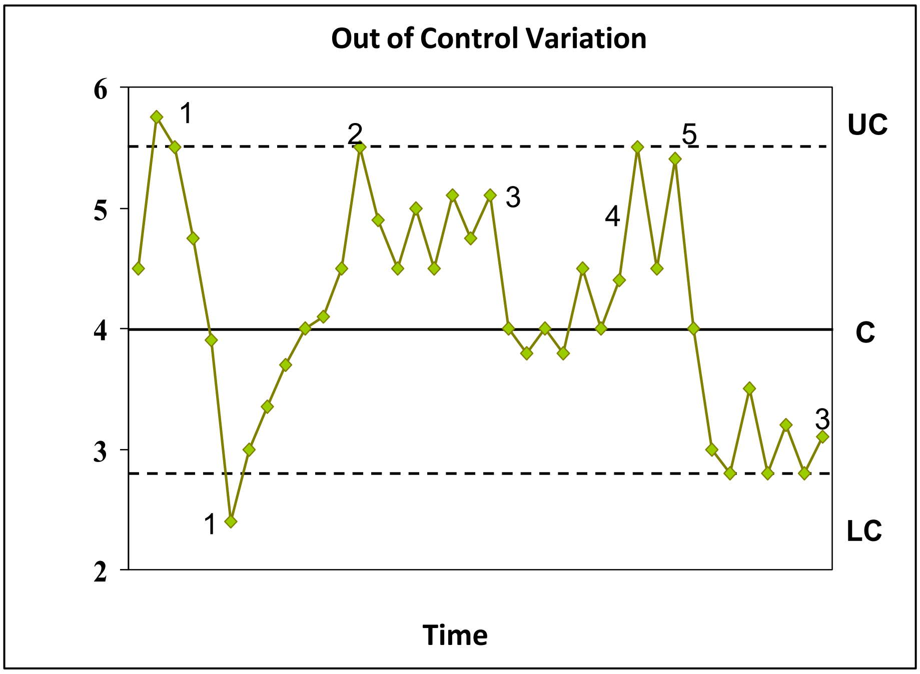


Figure 17: Control Charts Example

Note that Poka-Yoke may be a better form of maintaining control as it could prevent the mistake from occurring in the first place. In case of a control chart, we have to constantly monitor the control chart to determine if any special causes have occurred.

8 Appendix

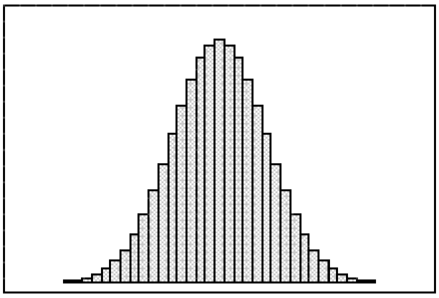
Binomial Distribution

In this distribution, the random variable only takes two values – such as a coin toss (heads or tails). For example, if we are working with defectives in a process, we can have parts that are defective or not defective – hence only two possible values.

If we have a series of coin tosses, let's say we have n coin tosses and the probability of occurrence of head is p, then the random variable X is said to have a binomial distribution with parameters n and p. The random variable can take on values 0, 1, 2, ..., n and counts the number of successes (where getting a head can be termed as success). The following conditions have to be met for using a Binomial distribution:

- The number of trials is fixed
- Each trial is independent
- Each trial has one of two outcomes: event or non-event
- The probability of an event is the same for each trial

Suppose a process produces 2% defective items. You are interested in knowing how likely is it to get 3 or more defective items in a random sample of 25 items selected from the process. The number of defective items (X) follows a binomial distribution with n = 25 and p = 0.02.



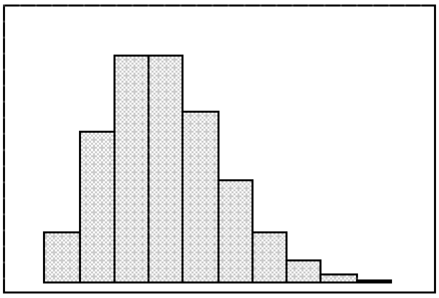
One of the properties of a binomial distribution is that when n is large and p is close to 0.5, the binomial distribution can be approximated by the standard normal distribution. For this graph, n = 100 and p = 0.5.

Poisson distribution

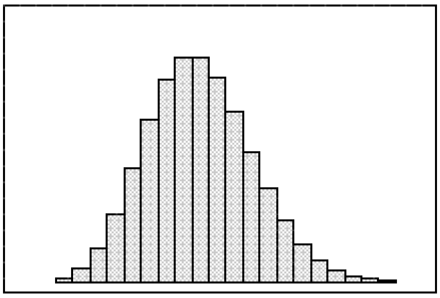
Describes the number of times an event occurs in a finite observation space. For example, a Poisson distribution can describe the number of defects in the mechanical system of an airplane or the number of calls to a call center. The Poisson distribution is often used in quality control, reliability/survival studies, and insurance.

The Poisson distribution is defined by one parameter: lambda. This parameter equals the mean and variance. As lambda increases, the Poisson distribution approaches a normal distribution. Whenever, we are working with defects or when the exact probability of an event is not know (only the average), then we are usually working with the Poisson distribution. For example, if the average number of road accidents in a state is 2 per day, then the exact probability is not know, we would use the Poisson distribution function in this case.

Lambda = 3



Lambda = 10



A variable follows a Poisson distribution if the following conditions are met:

- Data are counts of events (non-negative integers with no upper bound).
- All events are independent.
- Average rate does not change over the period of interest.

The Poisson distribution is similar to the binomial distribution because they both model counts of events. However, the Poisson distribution models a finite observation space with any integer number of events greater than or equal to zero. The binomial distribution models a fixed number of discrete trials from 0 to n events

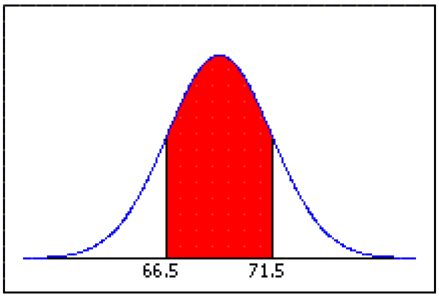
Normal distribution

A bell-shaped curve that is symmetric about its mean. The normal distribution is the most common statistical distribution because approximate normality arises naturally in many physical, biological, and social measurement situations. Many statistical analyses require that the data come from normally distributed populations.

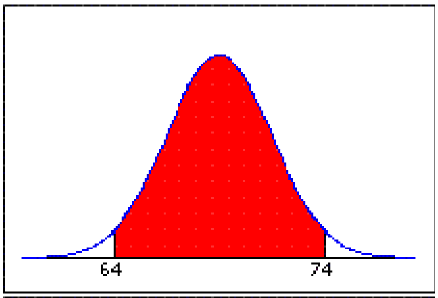
For example, the heights of all adult males residing in the state of Pennsylvania are approximately normally distributed. Therefore, the heights of most men will be close to the mean height of 69 inches. A similar number of men will be just taller and just shorter than 69 inches. Only a few will be much taller or much shorter.

The mean (μ) and the standard deviation (σ) are the two parameters that define the normal distribution. The mean is the peak or centre of the bell-shaped curve. The standard deviation determines the spread in the data. Approximately, 68% of observations are within +/- 1 standard deviation of the mean; 95% are within +/- 2 standards deviations of the mean; and 99% are within +/- 3 standard deviations of the mean.

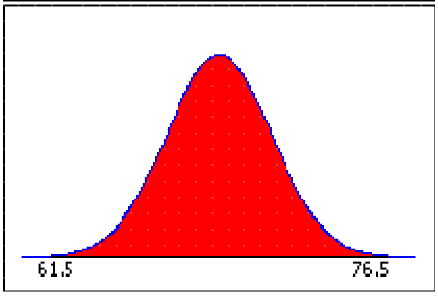
For the height of men in Punjab, the mean height is 69 inches and the standard deviation is 2.5 inches. For a continuous distribution, like to normal curve, the area under the probability density function (PDF) gives the probability of occurrence of an event.



Approximately 68% of Punjab men are between 66.5 (m - 1s) and 71.5 (m + 1s) inches tall.



Approximately 95% of Punjab men are between 64 (m - 2s) and 74 (m + 2s) inches tall.



Approximately 99% of Punjab men are between 61.5 (m - 3s) and 76.5 (m + 3s) inches tall.

9 Common Six Sigma Acronyms

ANOVA	Analysis of Variance
COPQ	Cost of Poor Quality
C_P, C_{PK}	Process Capability Indices (Short Term)
DMADV	Define, Measure, Analyze, Design, Validate/Verify
DMAIC	Define, Measure, Analyze, Improve, Control
DOE	Design of Experiments
DPMO	Defects per Million Opportunities
DPU	Defects per Unit
FMEA	Failure Modes & Effects Analysis
IDOV	Identify, Design, Optimize, Validate/Verify
Kaizen	Continuous Improvement
KPI	Key Performance Indicator
MSA	Measurement Systems Analysis
Muda	Waste
PDCA	Plan Do Check Act
P_P, P_{PK}	Process Capability Indices (Long Term)
s	Sample Standard Deviation