# Certified Six Sigma - Green Belt Professional Sample Material

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# 1. SIX SIGMA AND ORGANIZATION

Six sigma is a method on quality, which is focused on results. It's also a technique of measurements which results in lower defects which convert into cost savings and competitive advantage.

Sigma (σ), is an mathematical symbol representing one standard deviation from the average or mean. Most control charts set their range at +3σ, but Six Sigma extends three more standard deviations. With six sigma, there are only 3.4 parts per million (PPM) defective. A 6 Sigma level process is operating at 99.9997% quality level.

## 1.1. Six Sigma and Organizational Goal

Six Sigma is defined as a methodology that aims at a quasi-perfect production process. It is also defined as a methodology that aims at a rate of 3.4 defects per million opportunities (DPMO).

In the design phase of any process, the customers' needs and expectations are identified and translated into Critical-To-Quality (CTQ) characteristics. These characteristics are put into the products' design so as to manufacture or deliver it consistently and economically. But variability comes during delivery or manufacture hence, tolerance levels are specified thus, the company should measure and control the variations. Then the process performance is measured to know how the output against specified limits by the process capability or the ability of the process to generate products that are within the specified limits, and the process stability or company's ability to predict the process performance based on past experience. Usually the SPC is used with sample being tested at specified intervals and estimation is derived for whole to know number of defects.

### Continuous Improvement

Continuous improvement involves constantly identifying and eliminating the causes that prevent a system or process from functioning at its optimum level. The concept of continuous improvement originated in Japan in the 1970s. It was adopted in many countries, including U.S.A., in the early 1980s. Continuous improvement—and consequent customer satisfaction—is the principle on which the concept of Lean manufacturing is developed. When this principle is combined with just-in-time technique, it results to Lean manufacturing. Continuous improvement helps an organization to add value to its products and services by reducing defects, mistakes, etc. and to maximize its potential. As continuous improvement requires constant ongoing efforts, it is essential that the top management takes a long term view and commits itself for its implementation.

Continuous improvement enables organizations identify and rectify problems as and when they occur. Thus, it ensures smooth functioning of the processes. Many modern quality improvement models or tools like control charts, sampling methods, process capability measures, value analysis, design of experiments, etc. have been influenced by the concept of continuous improvement.

### Six Sigma History

History of six sigma encompassed various events which shaped it's formation and spread. Six sigma has evolved over time. It's more than just a quality system like TQM or ISO. The events for six sigma evolution are as

- ✓ Carl Frederick Gauss (1777-1855) introduced the concept of the normal curve.

- ✓ Walter Shewhart in 1920's showed that three sigma from the mean is the point where a process requires correction.
- ✓ Following the defeat of Japan in World War II, America sent leading experts including Dr. W. Edwards Deming to encourage the nation to rebuild. Leveraging his experience in reducing waste in U.S. war manufacture, he offered his advice to struggling emerging industries.
- ✓ By the mid-1950s, he was a regular visitor to Japan. He taught Japanese businesses to concentrate their attention on processes rather than results; concentrate the efforts of everyone in the organization on continually improving imperfection at every stage of the process. By the 1970s many Japanese organizations had embraced Deming's advice. Most notable is Toyota which spawned several improvement practices including JIT and TQM.
- ✓ Western firms showed little interest until the late 1970s and early 1980s. By then the success of Japanese companies caused other firms to begin to re-examine their own approaches and Kaizen began to emerge in the U.S.
- ✓ Many measurement standards (Zero Defects, etc.) later came on the scene but credit for coining the term "Six Sigma" goes to a Motorola engineer named Bill Smith. ("Six Sigma" is also a registered trademark of Motorola). Bill Smith, along with Mikel Harry from Motorola, had written and codified a research report on the new quality management system that emphasized the interdependence between a product's performance in the market and the adjustments required at the manufacturing point.

Various models and tools emerged which are

- ✓ Kaizen – It refers to any improvement, one-time or continuous, large or small
- ✓ TQM – It is Total Quality Management with Organization management of quality consisting of 14 principles
- ✓ PDCA Cycle - Edward Deming's Plan Do Check Act cycle
- ✓ Lean Manufacturing – It focuses on the elimination of waste or "muda" and includes tools such as Value Stream Mapping, the Five S's, Kanban, Poka-Yoke
- ✓ JIT– It is Just in Time Business or catering to needs of customer when it occurs.
- ✓ Six Sigma – It is designed to improve processes and eliminate defects; includes the DMAIC and DMADV models inspired by PDCA

## Quality Pioneers

Various pioneers emerged who helped shape quality principles and laid the foundations for six sigma. They included

<u>Walter A. Shewhart</u> - He is the pioneer of Modern Quality Control who, recognized the need to separate variation into assignable and un-assignable causes. He is the founder of the control chart and originator of the plan-do-check-act cycle. He was the first to successfully integrate statistics, engineering, and economics and defined quality in terms of objective and subjective quality.

<u>Dr. W. Edwards Deming</u> – He studied under Shewhart at Bell Laboratories and major contributions includes developing 14 points on Quality Management, a core concept on implementing total quality management, is a set of management practices to help companies increase their quality and productivity. The 14 points are

- ✓ Create constancy of purpose for improving products and services.
- ✓ Adopt the new philosophy.
- ✓ Cease dependence on inspection to achieve quality.
- ✓ End the practice of awarding business on price alone; instead, minimize total cost by working with a single supplier.
- ✓ Improve constantly and forever every process for planning, production and service.
- ✓ Institute training on the job.
- ✓ Adopt and institute leadership.
- ✓ Drive out fear.
- ✓ Break down barriers between staff areas.
- ✓ Eliminate slogans, exhortations and targets for the workforce.
- ✓ Eliminate numerical quotas for the workforce and numerical goals for management.
- ✓ Remove barriers that rob people of pride of workmanship, and eliminate the annual rating or merit system.
- ✓ Institute a vigorous program of education and self-improvement for everyone.
- ✓ Put everybody in the company to work accomplishing the transformation.

<u>Joseph Juran</u> - His major contributions are directing most of his work at executives and the field of quality management and developing the "Juran Trilogy" for managing quality, as Quality planning, quality control, and quality improvement. He also enlightened the world on the concept of the "vital few, trivial many" which is the foundation of Pareto charts.

<u>Philip Crosby</u> - He stressed on Quality management and four absolutes of quality including

- ✓ Quality is defined by conformance to requirements.
- ✓ System for causing quality is prevention not appraisal.
- ✓ Performance standards of zero defects not close enough.
- ✓ Measurement of quality is the cost of nonconformance.

<u>Arman Feigenbaum</u> - He developed a systems approach to quality (all organizations must be focused on quality) by emphasizing that costs of quality may be separated into costs for prevention, appraisal, and failures (scrap, warranty, etc.)

<u>Kaoru Ishikawa</u> - He developed the concept of true and substitute quality characteristics as

- ✓ True characteristics are the customer's view
- ✓ Substitute characteristics are the producer's view
- ✓ Degree of match between true and substitute ultimately determines customer satisfaction

He also advocated of the use of the 7 tools and advanced the use of quality circles or worker quality teams. He also developed the concept of Japanese Total Quality Control

- ✓ Quality first and not short term profits.
- ✓ Next process is the customer.
- ✓ Use facts and data to make presentations.
- ✓ Respect for humanity as a management philosophy of full participation

Genichi Taguchi - He developed the quality loss function (deviation from target is a loss to society) and promoted the use of parameter design (application of Design of experiments) or robust engineering. The goal is to develop products and processes that perform on target with smallest variation insensitive to environmental conditions and the focus is on engineering the design.

## Value of Six Sigma

The Six Sigma concept was developed at Motorola in the 1980s. Six Sigma can be viewed as a philosophy, a technique, or a goal.

- ✓ Philosophy - Customer-focused breakthrough improvement in processes
- ✓ Technique - Comprehensive set of statistical tools and methodologies
- ✓ Goal - Reduce variation, minimize defects, shorten the cycle time, improve yield, enhance customer satisfaction, and boost the bottom line

Six sigma is not about quality for the sake of quality; it is about providing better value to customers, investors and employees. Six Sigma is a process of asking questions that lead to tangible and quantifiable answers that ultimately produce profitable results. There are four groups of quality costs, which are

- ✓ External failure cost: warranty claims, service cost
- ✓ Internal failure cost: the costs of labor, material associated with scrapped parts and rework
- ✓ Cost of appraisal and inspection: these are materials for samples, test equipment, inspection labor cost, quality audits, etc..
- ✓ Cost related to improving poor quality: quality planning, process planning, process control, and training.

Usually companies are at 3 Sigma level which translates to 25-40% of annual revenue being taken by cost of quality. Thus, if a company can improve its quality by 1 sigma level, its net income will increase hugely, approximately 10 percent net income improvement.

Furthermore, when the level of process complexity increases (eg. output of one sub-process feeds the input of another sub-process), the rolled throughput yield of the process will decrease, then the final outgoing quality level will decline, and the cost of quality will increase. Project teams with well-defined projects improve the company's profits.

## Mathematical Six Sigma

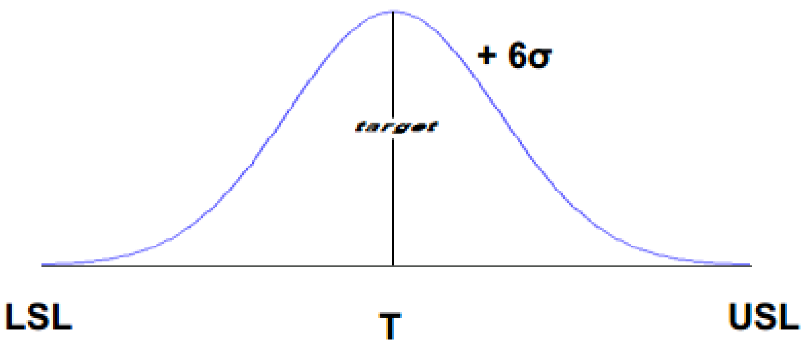
The term ‘Six Sigma’ is drawn from the statistical discipline ‘process capability studies’. Sigma, represented by the Greek alphabet ‘σ’, stands for standard deviation from the ‘mean’. ‘Six Sigma’ represents six standard deviations from the ‘mean.’ This implies that if a company produces 1,000,000 parts/units, and its processes are at Six Sigma level, less than 3.4 defects only will result. However, if the processes are at three sigma level, the company ends up with as many as 66,807 defects for every 1,000,000 parts/units produced.

The table below shows the number of defects observed for every 1,000,000 parts produced (also referred to as defects per million opportunities or DPMO).

| Sigma Level | Defects per million opportunities |
|---|---|
| Two Sigma | 308,507 DPMO |
| Three Sigma | 66,807 DPMO |
| Four Sigma | 6,210 DPMO |
| Five Sigma | 233 DPMO |
| Six Sigma | 3.4 DPMO |

Process standard deviation (σ) should be so minimal that the process performance should be able to scale up to 12σ within the customer specified limits. So, no matter how widely the process deviates from the target, it must still deliver results that meet the customer requirements. Few terms used are

- ✓ USL – It is upper specification limit for a performance standard. Any deviation beyond this is a defect.
- ✓ LSL – It is lower specification limit for a performance standard. Any deviation below this is a defect.
- ✓ Target – Ideally, this will be the middle point between USL and LSL.




Six Sigma approach is to find out the root causes of the problem, symbolically represented by Y = F(X). Here, Y represents the problem that occurs due to cause (s) X.

| Y | x1, x2, x3, ...., xn |
|---|---|
| Dependent | Independent |
| Customer related output | Input-process |
| Effect | Cause |
| Symptom | Problem |
| Monitor | Control |

## Benefits of Six Sigma

- ✓ Continuous defect reduction in products and services
- ✓ Enhanced customer satisfaction
- ✓ Performance dashboards and metrics
- ✓ Process sustenance
- ✓ Project based improvement, with visible milestones
- ✓ Sustainable competitive edge
- ✓ Helpful in making right decisions

## Business processes

A business process or a process is a group of tasks which result in a specific service or product for customers. It can be visualized with a flowchart or a process matrix. Business processes are fundamental to every company's performance and implement the business strategy. Understanding and optimizing the business process is the crux of six sigma.

Frequently, organizations treat the symptoms of a process performance issue without truly understanding the root cause or impact of the issue. Dissecting and truly understanding root cause for process performance is critical to effective process improvement which is can be accomplished by six sigma. Each process, have the three elements of inputs, process and outputs that affect its function. A business process is a collection of related activities that produce something of value to the organization, its stakeholders or its customers.

Having a standard model such as DMAIC (Define-Measure-Analyze-Improve-Control) makes process improvement and optimization much easier by providing the teams with an easy roadmap. This disciplined, structured, rigorous approach consists of steps which are linked logically to the previous step and to the next step. It is not enough for organizations to treat process improvement as one-time or periodic events. A sustaining focus on process management and continuous improvement is the key.

Types of Processes - Processes can be classified as management processes, operational processes and supporting processes.

- ✓ Management processes - These processes administer the operation of a system. Some examples of management processes are planning, corporate governance, etc.
- ✓ Operational processes - These processes create the primary value stream for the customers. Hence, they are also called 'core business processes'. Some examples of operational processes are purchasing of raw materials, manufacturing of goods, rendering of services, marketing, etc.
- ✓ Supporting processes - These processes support the core business processes of the organization. Some examples of supporting processes are accounting, technical support, etc.

These processes can be divided into many sub-processes that play their intended roles to successfully complete the respective head processes.

## Business System

A business system is a group of business processes which combine to form a single and identifiable unit of business as a whole. It is composed of processes, which in turn are composed of sub-processes and which are further composed of individual tasks.

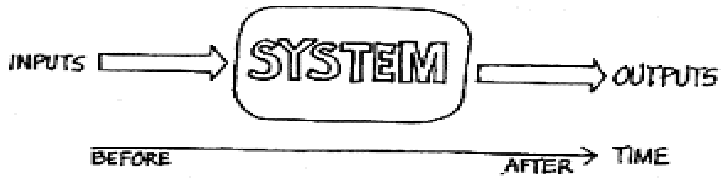
A business system is a system that implements a process or a set of processes. It ensures that all the processes operate smoothly without delays or lack of resources. Six sigma directs business systems to ensure that the processes, products, and services are subjected to continuous improvement and for which collection and analysis of data from processes is initiated.

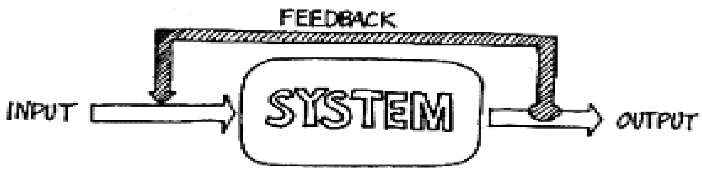
It is important to have an appropriate business system in place and the relevant processes under the system are well-documented. The documentation of the processes must be done in such a way that every task, activity, and their sequence are taken into account for proper execution as planned for in the business system.

## Process Control

Feedback received from process is used for process control thus, focusing on the input and output of the process for data collection. Every sub-process or task act as an input to next task or as output for previous one. Achieving optimum resources usage by a process though keeping quality output by

- ✓ Applying feedback loop to collect data from various process stages so as to apply improvisation
- ✓ Re-design the process for data collection, analysis and improvisation as part of the process.




A real-time feedback will initiate improvisation quickly. Tools like control chart helps in data collection and analysis as well.

## Six Sigma Green Belt's Responsibilities

A Six Sigma Green Belt has nearly identical responsibilities as a Black Belt when it comes to projects but they work on less complex challenges or problems than the Black Belt professionals. There are no dedicated Green Belt practitioners in any organization as, most Green Belts retain the positions they had prior to being trained in Six Sigma and use the new skills to improve their working environment and performance. The responsibilities of a Six Sigma Green Belt includes

- ✓ Project Management involving defining the project scope, marshal resources, setting up of goals, timelines and milestones and also reporting or updating stakeholders and executives.
- ✓ Task Management involving establishing the team's lean Sigma roadmap, leading the implementation of Six Sigma tools, managing team meetings, tracking and reporting team progress
- ✓ Team Management involving selecting team members, manage the team's organizational interfaces and ensuring the team is trained and equipped for their work.

## DMAIC Methodology

The Six Sigma methodology is conceptually based a five phase project. Each phase has a specific purpose and specific tools and techniques which aid in achieving the phase objectives as well as lead the Six Sigma professional to significant conclusions. The 5 Phases of the Six Sigma Methodology is called as DMAIC or the Define Phase, Measure Phase, Analyze Phase, Improve Phase and the Control Phase. All the five phases are discussed below.

Define Phase - The goal of Define is to establish the projects foundation and is the most important aspect of the Six Sigma project. Projects start with a current state challenge which is articulated in a quantifiable manner as well as the goal to achieve, is also determined.

After specification of problems and goals the remaining tasks of valuation, team, scope, project planning, time line, stakeholders, VOC/ VOB etc. are to be completed. Various tools used by the Define Phase are

- ✓ Project Charter
- ✓ Problem Statement
- ✓ Business Case
- ✓ Objective
- ✓ High level time line
- ✓ Project Scope
- ✓ Project Team
- ✓ Stakeholder Assessment
- ✓ Pareto Charts
- ✓ SIPOC
- ✓ VOC/VOB and CTQ's
- ✓ High Level Process Map

Measure Phase – In this phase baseline information is gathered about the process or product and achieve the following objectives

- ✓ Gather All possible x's
- ✓ Analyze measurement system and Data Collection Requirements
- ✓ Validate Assumptions and Improvement Goals
- ✓ Determine COPQ
- ✓ Refine Process Understanding
- ✓ Determine Process Capability
- ✓ Process Stability

This Phase involves the usage of following tools

- ✓ Process Maps, Value Stream Mapping
- ✓ Failure Modes and Effects Analysis (FMEA)
- ✓ Cause and Effect Diagram
- ✓ XY Matrix
- ✓ Basic Control Charts
- ✓ Six Sigma Statistics
- ✓ Basic Statistics
- ✓ Descriptive Statistics
- ✓ Normal Distributions
- ✓ Graphical Analysis
- ✓ Measurement Systems Analysis
- ✓ Variable Gage R&R

- ✓ Attribute Gage R&R
- ✓ Gage Linearity and Accuracy
- ✓ Gage Stability
- ✓ Process Capability (Cpk, Ppk) and Sigma
- ✓ Data collection plan

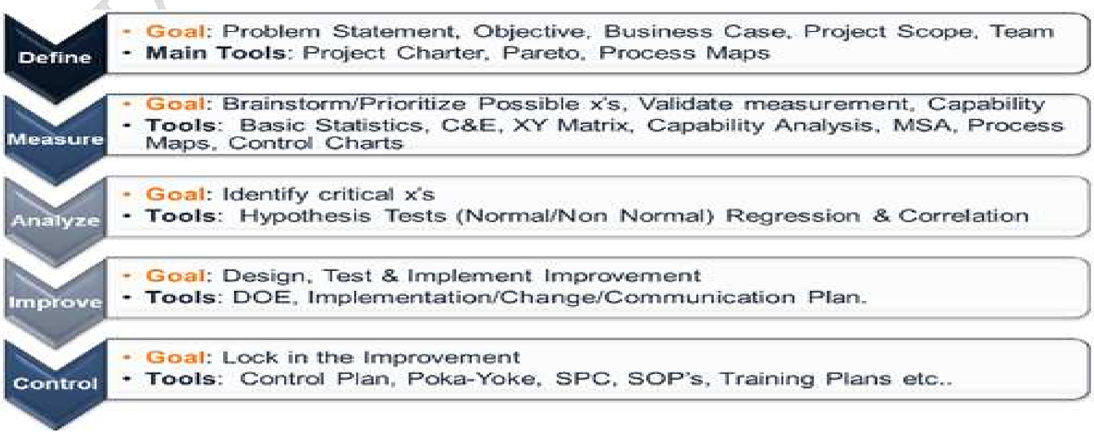
Analyze Phase – It entails establishing verified drivers by using statistics and higher order analytics to discover the fact-based relationship between the process performance and the x's or the root causes or drivers of improvement effort. Thus, resulting in establishment of hypothesis for improvements. This phase establishes transfer function Y=f(x) and validates list of critical X's and their impacts. The analyze phase also results in a beta improvement plan like pilot plan. This phase utilizes various tools like

- ✓ Hypothesis Testing
- ✓ Simple Linear Regression
- ✓ Multiple Regression

Improve Phase – This phase is aimed only on making the improvement like improving the designing, testing and implementing of the solution. It involves enlisting statistically proven results from active study or pilot, creating the improvement plan, updating the stakeholder assessment, revising the business case with investment ROI, risk assessment and adding new process capability. This phase uses tools like

- ✓ Design of Experiment (DOE)
- ✓ Implementation Plan
- ✓ Change Plan
- ✓ Communication Plan

Control Phase – It is the last phases of the Six Sigma methodology which establishes automated and managed mechanisms to maintain and sustain improvements in the process. A successful control plan also results in a reaction and mitigation plan with an accountability structure. It involves tools like control plan, training plans, poka-yoke and/or audit plans. The Six Sigma methodology is a complete system with tools and techniques built-in which ensures the Six Sigma practitioner to achieve success.



## Cost of Quality (COQ)

Cost of quality is the sum of various costs as that of appraisal costs, prevention costs, external failure costs, and internal failure costs. It is generally believed that investing in prevention of failure will decrease the cost of quality as failure costs and appraisal costs will be reduced. Understanding cost of quality helps organizations to develop quality conformance as a useful strategic business tool that improves their product, services & brand image. This is vital in achieving the objectives of a successful organisation.

COQ is primarily used to understand, analyze & improve the quality performance. COQ can be used by shop floor personnel as well as a management measure. It can also be used as a standard measure to study an organization's performance vis-à-vis another similar organisation and can be used as a benchmarking indices.

The various costs which constitute cost of quality are

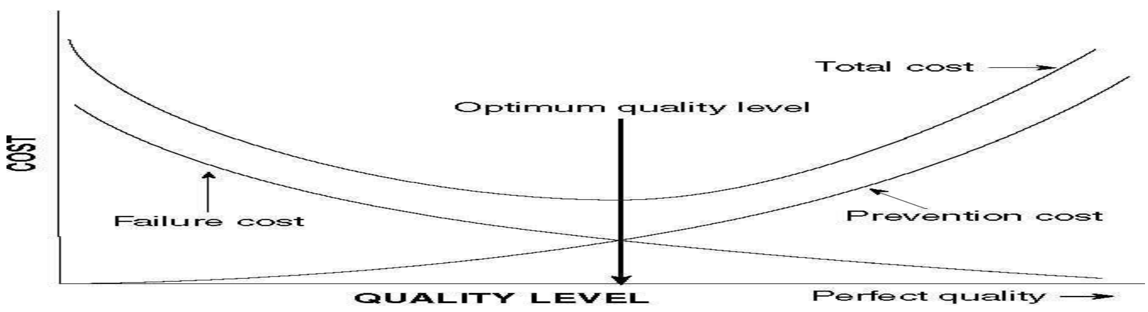
- ✓ Appraisal cost is the cost incurred because of inspecting the processes. The cost associated with checking and testing to find out whether it has been done first time right.
- ✓ Prevention cost is the cost incurred because of carrying out activities to prevent failures. The cost associated with planning and training associated with doing it first time right.
- ✓ External failure cost is the cost incurred because of the failure that occurred when the customer used the product.
- ✓ Internal failure cost is the cost incurred because of the failures within the organization.

Examples of the various costs are

- ✓ Prevention - Training Programme, Preventive Maintenance
- ✓ Appraisal - Depreciation of Test/ Measuring Equipment, Inspection Contracts
- ✓ Internal Failure - Scrap, Rework, Downtime, Overtime
- ✓ External Failure - Warranty, Allowances, Customer Returns, Customer Complaints, Product Liability, Lawsuits, Lost Sales

Identifying COQ can have several benefits, as

- ✓ It provides a standard measure across the organisation & also inter-organisation
- ✓ It builds awareness of the importance of quality
- ✓ It identifies improvement opportunities
- ✓ Being a cost measure, it is useful at shop floor as well as at management level



## Organizational Drivers and Metrics

Key Drivers – Performance measurement and analysis is the primary way to reduce wastages and maintain higher quality products or services. Various internal and external entities act as the key drivers for improvements. Internal key drivers include operational, workforce, governance and compliance performance, and the external key drivers include customer, service, competitive and financial performance.

Various performance measures are present but only those performance metrics need to be considered which represent the factors for improvisations in selected performances like financial or customer.

Voice Of the Customer (VOC) - It is the term used to describe the stated and unstated needs or requirements of the customer. It helps in listing the relative importance of features and benefits associated with the product or service thus, showing the expectations and promises that are both fulfilled and unfulfilled by the product or service. Voice of the Customer (VOC) is describes customer's feedback about their experiences with and expectations for the products or services.

Gathering VOC information can be done by
- ✓ Direct interviews of customers like site intercepts, personal interviews, focus groups, customer feedback forms, or structured online surveys.
- ✓ Indirect interviews with representatives like sales people or customer service representatives, who interface with the customer and report on their needs.

Conducting VOC helps by
- ✓ Customize products, services, add-ons and features to meet the needs and wants of customers
- ✓ No one becomes an industry leader without listening to the customer. Quality (customer perceived) is the leading driver of business success
- ✓ Maximize company's profit. Higher market share companies have higher profits

The Balanced Scorecard - It is the most widely used business performance measurement framework, introduced by Robert S. Kaplan and David P. Norton in 1992. Balanced scorecards were initially focused on finding a way to report on leading indicators of a business's health, they were refocused to measure the firm's strategy that directly relate to the firm's strategy. Usually the balanced scorecard is broken down into four sections, called perspectives, as

- ✓ The financial perspective - The strategy for growth, profitability and risk from the shareholder's perspective. It focuses on the ability to provide financial profitability and stability for private organizations or cost-efficiency/effectiveness for public organizations.
- ✓ The customer perspective - The strategy for creating value and differentiation from the perspective of the customer. It focuses on the ability to provide quality goods and services, delivery effectiveness, and customer satisfaction
- ✓ The internal business perspective - The strategic priorities for various business processes that create customer and shareholder satisfaction. It aims for internal processes that lead to "financial" goals

- ✓ The learning and growth perspective - The priorities to create a climate that supports organizational change, innovation and growth. It targets the ability of employees, technology tools and effects of change to support organizational goals.

The Balanced Scorecard is needed due to various factors, as

- ✓ Focus on traditional financial accounting measures such as ROA, ROE, EPS gives misleading signals to executives with regards to quality and innovation. It is important to look at the means used to achieve outcomes such as ROA, not just focus on the outcomes themselves.
- ✓ Executive performance needs to be judged on success at meeting a mix of both financial and non-financial measures to effectively operate a business.
- ✓ Some non-financial measures are drivers of financial outcome measures which give managers more control to take corrective actions quickly.
- ✓ Too many measures, such as hundreds of possible cost accounting index measures, can confuse and distract an executive from focusing on important strategic priorities. The balanced scorecard disciplines an executive to focus on several important measures that drive the strategy.

### Organizational Goals

Before a Six Sigma project can be executed, organizational strategic planning goals and objectives must be defined. Determining selection of appropriate projects and choosing an effective improvement model are crucial tasks that help to ensure company is pointed in the right direction.

The broad objectives of the organization must be aligned with its long term strategies. One of the techniques that an organization can use to align its objectives with long term strategies is 'hoshin planning'. Hoshin planning helps an organization to develop its business plan and deploy the same across the organization in order to reach the set goals.

Project selection is a testimony to a leader's role in successfully aligning the broad objectives of the organization with its long term strategies. A project selection committee or group can be formed to screen and select projects. It can include Champions, Master Black Belts, Black Belts, and important executive supporters.

The project selection committee sets the criteria to select the projects. The project selection criteria are framed on the basis of the key factors that define the business case and business need of an organization. After selecting the projects, the project selection committee matches the projects selected with teams assigned to execute them.

## 1.2. Lean Principles

Lean manufacturing focuses on lean philosophy which is about elimination of waste in all forms at the workplace. Specific lean methods include just-in-time inventory management, Kanban scheduling systems and 5S workplace organization.

Many of these concepts were developed by a Japanese company, Toyota which is an automobile manufacturer in the 1940s and these concepts became widespread for removing waste thus, graduating as best practices in many industries beyond automotive companies. Applying these principles to production has the potential for both improved profitability and increased complexity.

## Origins

Lean Manufacturing has evolved over times. In 1890's Frederick W. Taylor began to look at individual workers and work methods. Frank Gilbreth added Motion Study and invented Process Charting. Lillian Gilbreth introduced psychology by studying the motivations of workers and how attitudes affected the outcome of a process. These ideas led to waste elimination, a key component of JIT and Lean Manufacturing.

In 1910, Henry Ford developed and implemented the first comprehensive Manufacturing Strategy by arranging all the elements of a manufacturing system like people, machines, tooling and products, in a continuous system or an assembly line for manufacturing the Model T automobile.

## Toyota Production System

During 1949 and 1975, in Toyota Motor Company, Taichii Ohno and Shigeo Shingo, began to incorporate Ford production and other techniques into an approach called Toyota Production System or Just In Time. But, they found flaws in the Ford system, especially with treatment towards employees as Ford used employees only for muscle power.

The Toyota Production System (TPS) focuses on muri and muda. Muri focuses on the preparation and planning of the process, or what work can be eliminated in the design process. Muda are those waste steps and processes that add cost. Muri is used in new product design and muda is used to improve existing operations.

## Concept and Tools

Lean manufacturing is not just usage of few techniques or processes but a journey in itself which takes a holistic view of the organization and involves various phases which make use of various techniques and processes. The process for lean manufacturing involves following steps

- ✓ Define value from the customer's perspective
- ✓ Map the value stream
- ✓ Create flow by removing causes of waste
- ✓ Create pull if flow is difficult to achieve
- ✓ Measure and validate
- ✓ Practice continuous improvements

Mudas - Muda is a Japanese term meaning "waste" as, lean manufacturing is an Japanese management philosophy hence, Japanese terms and concepts are used extensively. There are 7 mudas or seven types of waste that are found in a manufacturing process which are

- ✓ Overproduction - Producing more than the customer requires is waste causing other wastes like inventory costs, manpower and conveyance to deal with excess product.
- ✓ Needless Inventory - Inventory at any point is a no value-add as it ties up financial resources of the company and is exposed to the risk of damage, obsolescence, spoilage, and quality issues. It also needs space and other resources for proper management and tracking.

- ✓ Defects - Defects and broken equipment results in defective products and subsequently customer dissatisfaction, which need more resources for solving.
- ✓ Non-value Processing – It is also called over-processing, for which more resources are wasted in production, their wasted movement and time. Any processing that does not add value to the product is waste like in-process protective packaging due to extra manufacturing steps.
- ✓ Excess Motion - Unnecessary motion due to poor workflow, poor layout, housekeeping, inconsistent work methods or lack of standardized procedures, is a waste.
- ✓ Transport and Handling – It is shipping damage and includes pallets not being properly stretch wrapped (wasted material), or a truck is not loaded to use floor space efficiently.
- ✓ Waiting - These are wastages in time, due to broken machinery, lack of trained staff, shortages of materials, inefficient planning and waiting for material.

<u>Waste Elimination Techniques</u> - Various waste elimination techniques which are used in lean manufacturing are listed, as

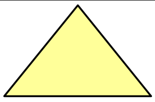
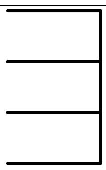
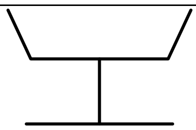
- ✓ Pull System – It is the technique for producing parts as per the customer's demand. Companies need to have a Push System or building products to stock as per sales forecast, without firm customer orders.
- ✓ Kanban – It is a method for maintaining an orderly flow of material. Kanban cards are used to indicate material order points, how much material is needed, from where the material is ordered, and to where it should be delivered.
- ✓ Total Quality Management – It is a management system for continuous improvement in all areas of a company's operation. It is applicable to every operation of the organization and involves employees.
- ✓ Quick Changeover (or SMED - Single Minute Exchange of Dies) – It is the technique for reducing changeover time to change a process from running a specific product manufacture to another. It enables flexibility in final product offerings and also to address smaller batch sizes.
- ✓ 5S or Workplace Organization – It is a systematic method for organizing and standardizing the workplace and is applicable to every function in an organization.
- ✓ Total Productive Maintenance – It focuses on proactive and progressive maintenance of equipments by utilizing the knowledge of operators, equipment vendors, engineering and support persons to optimize machine performance thus, drastically reducing breakdowns, unscheduled and scheduled downtime which results in improved utilization, higher throughput, and better product quality.
- ✓ Takt time is a measure of customer demand expressed in units of time and is calculated as Takt time = Available time per shift / Demand per shift or Cycle time/Number of People
- ✓ Visual Controls – They provide an immediate understanding (usually thirty seconds) of a condition or situation like what's happening with regards to production schedule, backlog, workflow, inventory levels, resource utilization, and quality. It includes kanban cards, lights, color-coded tools, lines delineating work areas and product flow, etc.
- ✓ Poka Yoke or Mistake Proofing - Poka Yoke is a quality management concept developed by a Matsushita manufacturing engineer named Shigeo Shingo to prevent human errors from occurring in the production line as, extensive automation and computerization is expensive. Poka yoke is implemented by using simple objects like fixtures, jigs, gadgets, warning devices, paper systems, and the like to prevent people from committing mistakes.

## Value-Added and Non-Value-Added Activities

Value refers to an activity for which customer will pay for or which is valued by the customer and rest are non-value activities. Value stream refers to the sequence of activities involved from customer's request ion to fulfillment and VSM records these activities as icons or symbols.

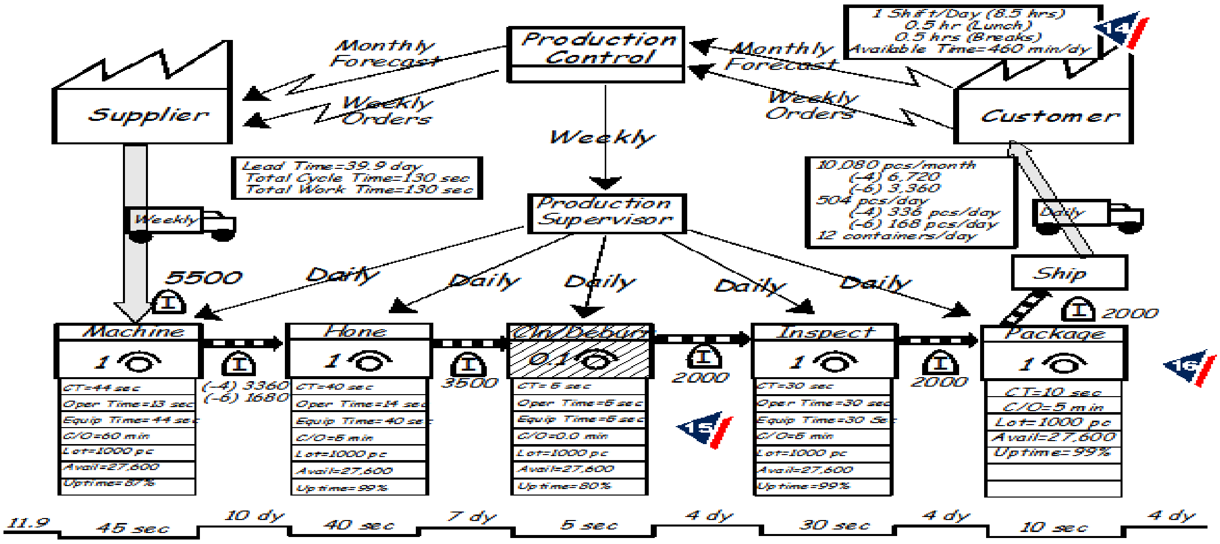
Value Stream Mapping (VSM) is a visualization tool oriented to understand and streamline work processes using icons and symbols to depict various elements and improve the flow of material and information. It helps in identifying and decreasing waste or non-value addition, in the process. It can also be used as a strategic planning tool and a change management tool other than a communication tool.

Few icons used for mapping and development of VSM, includes

| Icon | Name | Description |
|---|---|---|
|  | Inventory | This is a material Queue of products that are not being processed. It represents storage of raw materials as well as finished goods. The time period may be listed below the icon. |
|  | Supermarket | This is an inventory "supermarket" that contains some inventory available to downstream customers enabling them to select what they need. The next process or customer would pull from this inventory. |
|  | Go See Scheduling | Glasses represent collecting information visually. It can also indicate informal Scheduling. |
|  | Kanban Post | This represents a location for kanban signal pickup. |

<u>Developing the VSM</u> - VSM mapping involves step by step development of the VSM state map whether a present or of future state map and involves the following steps

- ✓ Draw customer, supplier and production control icons.
- ✓ Enter customer requirements and calculate daily production required.
- ✓ Draw outbound shipping icon and truck with delivery frequency.
- ✓ Draw inbound shipping icon, truck and delivery frequency.
- ✓ Add process boxes, in sequence, left to right, and data boxes below.
- ✓ Add communication arrows with methods and frequencies.
- ✓ Obtain process attributes and add data boxes.
- ✓ Add operator symbols, inventory locations and levels in days of demand graph at bottom.
- ✓ Add push, pull and FIFO icons.
- ✓ Add working hours, cycle times (CT) and lead times.
- ✓ Calculate total cycle lead time.




## 5S

5S is a discipline for creating and maintaining a clutter- free, clean, organized safe and high - performance workplace in 5 steps, which are seiri, seiton, seiso, seiketsu and shitsuke.

- ✓ Seiri - Sorting out: Clean out the work area, keeping what is necessary in the work area, relocating or discarding what is not
- ✓ Seiton - Systematic arrangement / Set limits and Locations: Arrange needed items so they are easy to find, use and return
- ✓ Seiso - Shine and Sweep: Clean and care for equipment area
- ✓ Seiketsu - Standardization: Make all work areas similar
- ✓ Shitsuke - Self-Discipline / Sustain: Make these rules natural and instinctual

## Theory of Constraints (TOC)

It is a methodology for identifying the most important limiting factor (i.e. constraint) that stands in the way of achieving a goal and then systematically improving that constraint until it is no longer the limiting factor. It was first published in The Goal by Eliyahu M. Goldratt and Jeff Cox in 1984. TOC conceptually models the manufacturing system as a chain, and advocates focusing on its weakest link. Goldratt defines a five-step process that a change agent can use to strengthen the weakest link, or links, which includes

- ✓ Identify the System Constraint - The part of a system that constitutes its weakest link can be either physical or a policy.
- ✓ Decide How to Exploit the Constraint - Goldratt instructs the change agent to obtain as much capability as possible from a constraining component, without undergoing expensive changes.
- ✓ Subordinate Everything Else - The non-constraint components of the system must be adjusted to a "setting" that will enable the constraint to operate at maximum effectiveness. Once this has been done, the overall system is evaluated to determine if the constraint has shifted to another component. If the constraint has been eliminated, the change agent jumps to step five.

- ✓ Elevate the Constraint - "Elevating" the constraint refers to taking whatever action is necessary to eliminate the constraint. This step is only considered if steps two and three have not been successful. Major changes to the existing system are considered at this step.
- ✓ Return to Step One, But Beware of "Inertia"

## 1.3. Design for Six Sigma (DFSS)

Design for Six Sigma can be seen as a subset of Six Sigma focusing on preventing problems by going upstream to recognize that decisions made during the design phase profoundly affect the quality and cost of all subsequent activities to build and deliver the product. Early investments of time and effort pay off in getting the product right the first time. DFSS adds a new, more predictive front end to Six Sigma. It describes the application of Six Sigma tools to product development and process design efforts with the goal of "designing in" Six Sigma performance capability. The intension of DFSS is to bring such new products and/or services to market with a process performance of around 4.5 sigma or better, for every customer requirement.

### Quality Function Deployment (QFD)

Quality Function Deployment is a method for prioritizing and translating customer inputs into designs and specifications for a product, service, and/or process. While the detail of the work involved in QFD can be both complex and exhaustive, the essentials of the QFD method are based on common-sense ideas and tools. QFD is a planning tool that relates a list of delights, wants, and needs of customers to design technical functional requirements.

With the application of QFD, possible relationships are explored between quality characteristics as expressed by customers and substitute quality requirements expressed in engineering terms. In the context of DFSS, these requirements critical-to characteristics, which include subsets such as critical-to-quality (CTQ) and critical-to-delivery (CTD). In the QFD methodology, customers define the product using their own expressions, which rarely carry any significant technical terminology. The voice of the customer can be discounted into a list of needs used later as input to a relationship diagram, which is called QFD's house of quality.

One major advantage of a QFD is the attainment of shortest development cycle, which is gained by companies with the ability and desire to satisfy customer expectation. The other significant advantage is improvement gained in the design family of the company, resulting in increased customer satisfaction. QFD is a robust method having many variations in applications, as

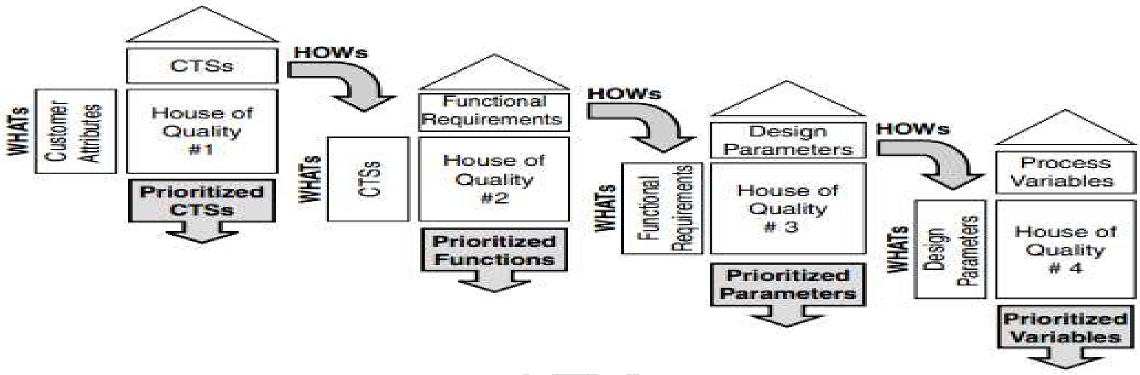
- ✓ Prioritize and select improvement projects based on customer needs and current performance
- ✓ Assess a process's or product's performance versus competitors
- ✓ Translate customer requirements into performance measures
- ✓ Design, test, and refine new processes, products, and services

QFD uses various other methods like Voice of the Customer input to Design of Experiments, to work well. A special multidimensional matrix, also called as the "House of Quality," is the best-known element of the QFD method. A full QFD product design project will involve a series of these matrices, translating from customer and competitive needs to detailed process specifications. QFD concept involves two core concepts, which are

The QFD Cycle - An iterative effort to develop operational designs and plans in four phases of

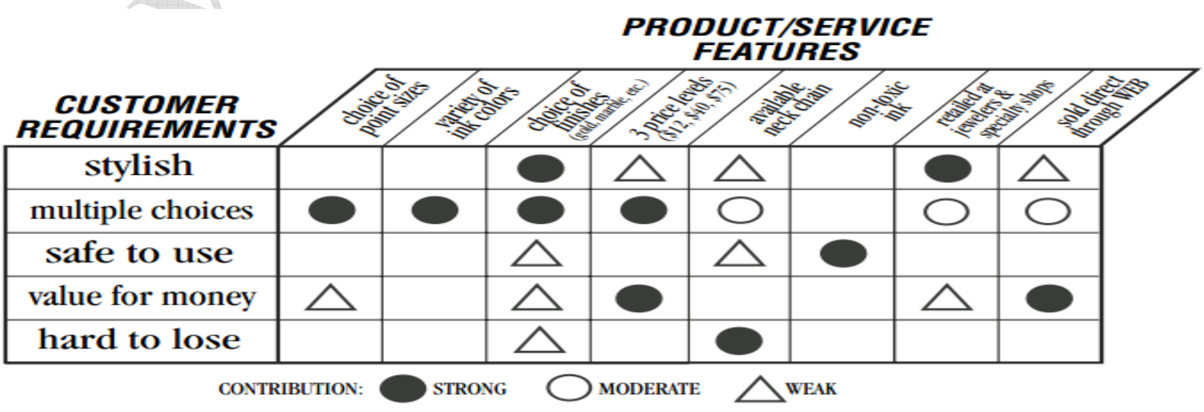
- ✓ Translate customer input and competitor analysis into product or service features.
- ✓ Translate product/service features into product/service specifications and measures.
- ✓ Translate product/service specifications and measures into process design features.
- ✓ Translate process design features into process performance specifications and measures.

QFD is accomplished by multidisciplinary DFSS teams using a series of charts to deploy critical customer attributes throughout the phases of design development. QFD is usually deployed over four phases. The four phases are phase 1—CTS planning, phase 2—functional requirements, phase 3—design parameters planning, and phase 4—process variables planning, as shown in the figure below.




Prioritization and Correlation - Detailed analysis of the relationships among specific needs, features, requirements, and measures. Matrices like the House of Quality or the simple L-Matrix keep this analysis organized and document the rationale behind the design effort.

The QFD Cycle develops the links from downstream Ys (Customer Requirements and Product Specifications) back to upstream Xs (Process Specifications) in the design process itself. With an existing process or product, it can be used to clarify and document those relationships if they've never been investigated before. Another benefit of the House of Quality is a "diagonal" relationship test afforded by the matrix, testing combinations that may not have been considered by our standard human "linear" thought processes. An example is shown below



QFD analysis is conducted in six steps as

- ✓ It starts with the articulation of customer requirements. Techniques used could be interviewing, observation, prototyping, conceptual modeling, etc. The data from marketing research are also used. These requirements are also known as the "What's".
- ✓ In the second step, the company's current product is ranked against the competitors.
- ✓ Next, the team looks at Product/Process Characteristics, in other words, the "How's" of meeting the customer requirements. Candidate CCR's are listed across the top and for each their relevance is considered and ranked as to which will address customer needs.
- ✓ Then, the team relates customer and technical requirements with ratings such as "high", "moderate", "low", and "no" correlation. The team evaluates the degree to which customer wants and needs are addressed by the product or process characteristics.
- ✓ In the fifth step, the roof of the "House" focuses on relationships among product/process characteristics. It shows whether the "How's" reinforce or conflict with one another.
- ✓ In last, the team summarizes the key conclusions. It ranks the relevance of product or process characteristics to the attainment of customers' wants or needs.

## Design And Process Failure Mode And Effects Analysis (DFMEA and PFMEA)

FMEA is a systematic, proactive method for evaluating a process to identify where and how it might fail and to assess the relative impact of different failures, in order to identify the parts of the process that are most in need of change. FMEA includes review of the following

- ✓ Steps in the process
- ✓ Failure modes (What could go wrong?)
- ✓ Failure causes (Why would the failure happen?)
- ✓ Failure effects (What would be the consequences of each failure?)

FMEA evaluates processes for possible failures and to prevent them by correcting the processes proactively rather than reacting to adverse events after failures have occurred. FMEA is also useful in evaluating new process prior to implementation and in assessing impact of changes to an existing process. FMEA usually involves the following steps

- ✓ Select a process to evaluate with FMEA - Evaluation using FMEA works best on processes that do not have too many sub-processes, instead of doing an FMEA on a large and complex process.
- ✓ Recruit a multidisciplinary team - Be sure to include everyone who is involved at any point in the process.
- ✓ Have the team meet together to list all of the steps in the process - Number every step of the process, and be as specific as possible. It may take several meetings for the team to complete this part of the FMEA, depending on the number of steps and the complexity of the process. Flowcharting can be a helpful tool for outlining the steps. When finished, be sure to obtain consensus from the group. The team should agree that the steps enumerated in the FMEA accurately describe the process.
- ✓ Have the team list failure modes and causes - For each step in the process, list all possible failure modes, anything that could go wrong, including minor and rare problems. Then, for each failure mode listed, identify all possible causes.

- ✓ For each failure mode, have the team assign a numeric value (known as the Risk Priority Number, or RPN) for likelihood of occurrence, likelihood of detection, and severity. Assigning RPNs helps the team prioritize areas to focus on and can also help in assessing opportunities for improvement. For every failure mode identified, the team should answer as a group with consensus on all values assigned to the following questions
  - ✓ Likelihood of occurrence: How likely is it that this failure mode will occur? - Assign a score in 1 and 10, with 1 meaning "very unlikely to occur" and 10 meaning "very likely to occur."
  - ✓ Likelihood of detection: If this failure mode occurs, how likely is it that the failure will be detected? - Assign a score between 1 and 10, with 1 meaning "very likely to be detected" and 10 meaning "very unlikely to be detected."
  - ✓ Severity: If this failure mode occurs, how likely is it that harm will occur? - Assign a score between 1 and 10, with 1 meaning "very unlikely that harm will occur" and 10 meaning "very likely that severe harm will occur." In patient care examples, a score of 10 for harm often denotes death.
- ✓ Evaluate the results - To calculate the Risk Priority Number (RPN) for each failure mode, multiply the three scores obtained (the 1to 10 score for each of likelihood of occurrence, detection, and severity). The lowest possible score will be 1 and the highest 1,000. Identify the failure modes with the top 10 highest RPNs. These are the ones the team should consider first as improvement opportunities. To calculate the RPN for the entire process, simply add up all of the individual RPNs for each failure mode.
- ✓ Use RPNs to plan improvement efforts - Failure modes with high RPNs are probably the most important parts of the process on which to focus improvement efforts. Failure modes with very low RPNs are not likely to affect the overall process very much, even if eliminated completely, and they should therefore be at the bottom of the list of priorities.

| Steps in the Process | Failure Mode | Failure Causes | Failure Effects | Likelihood of Occurrence (1–10) | Likelihood of Detection (1–10) | Severity (1–10) | Risk Priority Number (RPN) | Actions to Reduce Occurrence of Failure |
|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |
| 6 | | | | | | | | |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |
| 11 | | | | | | | | |
| 12 | | | | | | | | |
| 13 | | | | | | | | |
| 14 | | | | | | | | |
| 15 | | | | | | | | |
| | | | | | | | Total RPN (sum of all RPNs): | |

- ✓ Failure Mode: What could go wrong?
- ✓ Failure Causes: Why would the failure happen?
- ✓ Failure Effects: What would be the consequences of failure?
- ✓ Likelihood of Occurrence: 1–10, 10 = very likely to occur
- ✓ Likelihood of Detection: 1–10, 10 = very unlikely to detect
- ✓ Severity: 1–10, 10 = most severe effect
- ✓ Risk Priority Number (RPN): Likelihood of Occurrence × Likelihood of Detection × Severity

Design FMEA (DFMEA) – It is used to analyze designs before they are released to production. In the DFSS algorithm, a DFMEA should always be completed well in advance of a prototype build. The input to DFMEA is the array of functional requirements. The outputs are

- ✓ List of actions to prevent causes or to detect failure modes and
- ✓ History of actions taken and future activity.

The DFMEA helps the DFSS team in

- ✓ Estimating the effects on all customer segments
- ✓ Assessing and selecting design alternatives
- ✓ Developing an efficient validation phase within the DFSS algorithm
- ✓ Inputting the needed information for Design for X (DFMA, DFS,DFR, DFE, etc.)
- ✓ Prioritizing the list of corrective actions using strategies such as mitigation, transferring, ignoring, or preventing the failure modes
- ✓ Identifying the potential special design parameters (DPs) in terms of failure
- ✓ Documenting the findings for future reference

Process FMEA (PFMEA) – It is used to analyze manufacturing, assembly, or any other processes such as those identified as transactional DFSS projects. The focus is on process inputs. Software FMEA documents and addresses failure modes associated with software functions. The PFMEA is a valuable tool available to the concurrent DFSS team to help them in

- ✓ Identifying potential manufacturing/assembly or production process causes in order to place controls on either increasing detection, reducing occurrence, or both
- ✓ Prioritizing the list of corrective actions using strategies such as mitigation, transferring, ignoring, or preventing the failure modes
- ✓ Documenting the results of their processes
- ✓ Identifying the special potential process variables (PVs), from a failure standpoint, which need special controls

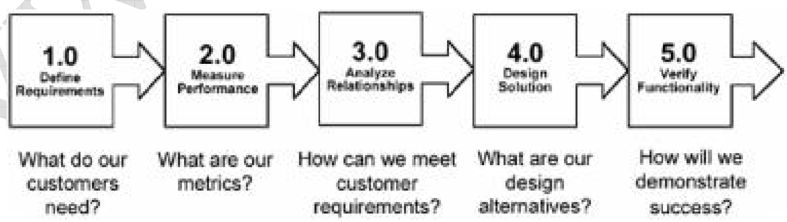
## DFSS Roadmap

IDOV and DMADV helps in improving and extending DFSS. Both IDOV and DMADV are discussed.

IDOV - IDOV stands for Identify, Design, Optimize and Verify. It is a variant of DFSS (Design For Six Sigma) but, different from DMAIC (define, measure, analyze, improve and control). It consists of four different phases as

- ✓ Identify Phase - It identifies specific customer needs, based on which a product or business process will be designed. It is essential for launching a new product or service and involves various activities as, defining VOC, developing a team and team charter, performing competitive analysis and identifying CTQs. Other crucial steps in this phase involve the identification of customer and product requirements, establishment of an appropriate business model, identification of technical requirements such as CTQs, allocation of roles and responsibilities. Some of the tools used are QFD, FMEA, target costing and benchmarking.
- ✓ Design Phase - It focus on functional requirements, development of alternate business processes, evaluation of available options and selection of the most appropriate business process based on CTQs identified earlier. It includes the formulation of concept design, identification of probable risk elements, and identification of design parameters by utilizing advanced simulation tools and formulation of procurement plans and manufacturing plans. Tools used in this phase include risk assessment, FMEA, engineering analysis and Design of experiments.
- ✓ Optimize Phase - This phase uses CTQs for calculating the tolerance level of a selected business process by simulation tools. It predicts the performance capability of a business process, optimizing existing design and developing alternative design elements. This phase may involve assessment of process capabilities, optimization of design parameters, development of design for robust performance and reliability, error proofing and establishment of tolerance measurement objectives. Tools usually used are manufacturing database and flow back tools, design for manufacturability, process capability models, Monte Carlo methods, tolerance measurement tools and Six Sigma tools.
- ✓ Validate Phase – It being the last phase, focus on testing and validating the selected design. Any changes to the design can be made in this phase. This phase involves prototype test and validation, assessment of performance, failure modes, reliability and risks, design iteration and final phase review.

<u>DMADV</u> – DMADV refers to Define, Measure, Analyze, Design and Verify. DMADV is one aspect of Design for Six Sigma (DFSS), which has evolved from the earlier approaches of continuous quality improvement and Six Sigma approach to reduce variation. A key component of the DMADV approach is an active 'toll gate' check sheet review of the outcomes of each of the five steps of DMADOV. It is depicted as




The application of DMADOV is aimed at creating a high-quality product keeping in mind customer requirements at every stage of the game. In general, the phases of DMADOV are

- ✓ Define phase – In this phase, wants and needs believed to be most important to customers are identified by historical information, customer feedback and other information sources. Teams are assembled to drive the process. Metrics and other tests are developed in alignment with customer information. The key deliverables are team charter, project plan, project team, critical customer requirements and design goals.

- ✓ Measure phase - The defined metrics are used to collect data and record specifications for remaining process. All the processes needed to successfully manufacture the product or service are assigned metrics for later evaluation. Technology teams test metrics and then apply them. The key deliverables are qualified measurement systems, data collection plan, capability analysis, refined metrics and functional requirements.
- ✓ Analyze phase - The result of the manufacturing process (i.e. finished product or service) is tested by internal teams to create a baseline for improvement. Leaders use data to identify areas of adjustment within the processes that will deliver improvement to either the quality or manufacturing process of a finished product or service. Teams set final processes in place and make adjustments as needed. The deliverables are data analysis, initial models developed, prioritized X's, variability quantified, CTQ flow-down and documented design alternatives.
- ✓ Design phase - The results of internal tests are compared with customer wants and needs. Any additional adjustments needed are made. The improved manufacturing process is tested and test groups of customers provide feedback before the final product or service is widely released. The deliverables includes validated and refined models, feasible solutions, trade-offs quantified, tolerances set and predicted impact.
- ✓ Verify phase - The last stage in the methodology is ongoing. While the product or service is being released and customer reviews are coming in, the processes may be adjusted. Metrics are further developed to keep track of on-going customer feedback on the product or service. New data may lead to other changes that need to be addressed so the initial process may lead to new applications of DMADV in subsequent areas. The key deliverables are detailed design, validated predictions, pilot / prototype, FMEA's, capability flow-up and standards and procedures.

The applications of these methodologies are generally rolled out over the course of many months, or even years. The end result is a product or service that is completely aligned with customer.