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Lean Six Sigma

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1. Introduction

Due to increased globalization and constant technological advances and other competitive pressures, the organizations have to accelerate the pace of change to adapt to new situations. This climate introduces opportunities and threats and Organizations have to innovate and strive for operational excellence. Six Sigma is the most popular quality and process improvement methodology which strives for elimination of defects in the processes whose origin is traced back to the pioneering and innovation work done at Motorola and its adoption by many companies including GE, Ford, General Motors, Xerox etc. The primary objective of Six Sigma is to reduce variations, in products and processes, to achieve quality levels of less than 3.4 defects per million opportunities (DPMO). The important point to be noted is reducing the defects involve measurements in terms of millions of opportunities instead of thousands. Six Sigma is a culmination of several decades of quality improvement efforts pursued by organizations world over due to pioneering work done by quality Gurus Shewart, Deming, Juran, Crosby, Ishikawa, Taguchi and others. Dr. W. Edward Deming, who is considered by many to be the "Father of modern Quality movement", was instrumental for transforming post war Japan into an economic giant because of helping for systematic introduction of quality improvement measures by Japanese companies. Dr. Deming had advocated popular quality improvement methods such as Total Quality Management (TQM), Plan-Do-Check-Act methodology, 14 point rules and elimination of 7 deadly sins and he helped organizations to achieve operational excellence with much customer focus. Later many US companies have gained much from Japanese experiences and ideas on quality improvement concepts.

The Six Sigma concepts and tools used can be traced back to sound mathematical and management principles of Gauss, Taylor, Gilberth and Ford for their contributions like Sigma and Normal distribution (Gaussian distribution), Taylor's Scientific Management, Gilberth's 'Time and Motion study' and Ford's mass production of cars using 'Assembly line' system.

Six Sigma when coupled with 'Lean Principles' is called 'Lean Six Sigma' which professes eliminating waste in process steps by using 'Lean Tools' which is based on Toyota Production System(TPS) which enhances value in Six Sigma implementation one step further by increasing speed by identifying and removing non-value adding steps in a process.

Execution of Lean Six Sigma project uses a structured method of approaching problem solving normally described by acronym 'DMAIC' which stands for Define, Measure, Analyze, Improve and Control.

Many organizations have achieved phenomenal success by implementing Lean Six Sigma. Lean and Six Sigma are conceptually sound technically fool proof methodologies and is here to stay and deliver break through results for a long time to come. Motorola had celebrated 20 years of Six Sigma in the year 2007 and as per Sue Reynard in an article in ISixSigma-Magazine, "Motorola is a company of inventions and Six Sigma which was invented at Motorola is a defect reduction methodology that aims for near perfection has changed the manufacturing game of Motorola, but it didn't stop there. As the Six Sigma has evolved during the ensuing 20 years, it had been adopted worldwide and has transformed the way business is done".

This chapter focuses and highlights overview and details of some of the important aspects of 'Lean Six Sigma' and the tools used to implement it in organizations to improve their bottom line by controlling variations in processes, reducing defects to near zero level and adopting lean principles. The chapter is organized on the following broad topics: the history of Six Sigma, the need for Six Sigma, Sigma Levels and motivation for Six Sigma, Lean thinking, Lean Six Sigma, DMAIC methodology, Six Sigma and Lean tools, and case studies on Lean Six Sigma implementations.

Six Sigma Tools are available as free open source templates which can be downloaded from the URLs which are given in the references at end of the chapter.

2. What is six sigma ?

Six Sigma is a quality improvement methodology invented at Motorola in 1980s and is a highly disciplined process improvement method that directs organizations to focus on developing and delivering near perfect products and services. Six Sigma is a statistical term that measures how far a given process deviates from perfection. The central idea behind Six Sigma is, if we are able to measure how many "defects" that exist in a process, it can be systematically figured out how to eliminate them and get close to "zero defects".

In the year 1985, Bill Smith, a Motorola Engineer coined the term 'Six Sigma', and explained that Six Sigma represents 3.4 defects per million opportunities is the optimum level to balance quality and cost. It is a real-breakthrough in quality improvement process where defects are measured against millions of opportunities instead of thousands which was the basis those days.

Leading companies are applying this bottom-line enhancing strategy to every function in their organizations. In the mid 1990s, Larry Bossidy of Allied Signal and Jack Welch of GE saw the potential in Six Sigma and applied it in their organizations which resulted in significant cost savings in progressive years. GE reports stated that Six Sigma had delivered \$300 million to its bottom line in 1997, \$750 million in 1998, and \$2 billion in 1999.

2.1 History of six sigma

The immediate origin of Six Sigma can be traced to its early roots at Motorola (Fig. 1), and specifically to Bill Smith (1929 - 1993). Bill Smith was an employee of Motorola and a Vice President and Quality Manager of Land based Mobile Product Sector, when he approached then chairman and CEO Bob Galvin in 1986 with his theory of latent defect.

The core principle of the latent defect theory is that *variation* in manufacturing processes is the main culprit for *defects*, and eliminating variation will help eliminate defects, which will in turn eliminate the wastes associated with defects, saving money and increasing customer satisfaction. Variation is measured in terms of sigma values or thresholds. The threshold

determined by Smith and agreed to by Motorola is 3.4 defects per million opportunities (3.4 DPMO), which is derived from sigma shifts from specifications.



Fig. 1. Bill Smith coins the term Six Sigma at Motorola.

Motorola adopted the concepts and went on to win the first ever *Malcolm Baldrige Excellence Award* in 1988, just two years after Bill Smith's introduction of Six Sigma.

3. Describing six sigma concept

Six Sigma is a method for improving quality by removing defects and their causes in business process activities. The method concentrates on those outputs which are important to customers and translates these customer needs into measurable requirements, the so called CTQs (Critical To Quality). An indicator for the CTQs is identified and a robust measurement system is established to obtain clean and precise data relating to the process. Once this is in place, one can compare actual process behaviour to the customer-derived specification and describe this in a statistical distribution (using mean, standard deviation [σ] or other indicators, dependent on the type of distribution).

3.1 Inputs and output

The objective of the Six Sigma concept is to gain knowledge about the transfer function of the process - the understanding of the relationship between the independent input variables (Xs) and the dependent output variable (Y). If the process is modelled as a mathematical equation, where Y is a function of X, i.e. $Y = f(X_1, X_2, \dots, X_n)$, then the output variable (Y) can be controlled by steering the input variables (Xs).

The Six Sigma drive for defect reduction, process improvement and customer satisfaction is based on the "statistical thinking" paradigm:

- All work occurs in a system of interconnected processes.
- All processes have inherent variation.
- Data analysis is used to understand the variation and to drive process improvement decisions.

3.2 Variation

Six Sigma is all about reducing the variation of a process. The more standard deviations (σ) - an indicator of the variation of the process - that fit between the mean of the distribution and the specification limits (as imposed by the customer), the more capable is the process. A Six Sigma process means that 6 standard deviations fit on each side of the mean, between the mean and the specification limits. 6 Sigma equates in percentage terms to 99.9997% accuracy or to 3.4 defects per million opportunities to make a defect. Fig 2 illustrates how Six Sigma quality is achieved by reducing variations in a process.

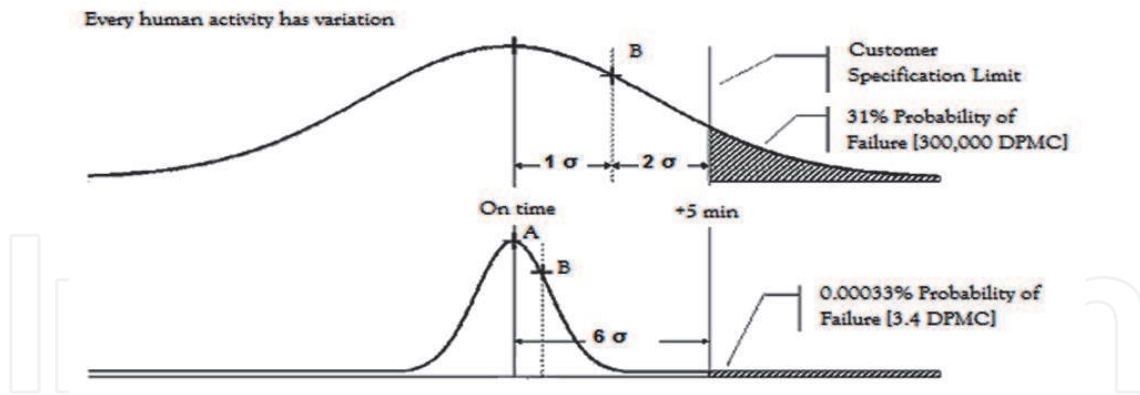


Fig. 2. Reducing variation in a process using Six Sigma

3.3 Normal curve and sigma

Six Sigma concepts can be better understood and explained using mathematical term Sigma and Normal Distribution. Sigma is a Greek symbol represented by " σ ". The bell shape curve shown in Fig. 3 is called "normal distribution" in statistical terms. In real life, a lot of frequency distributions follow normal distribution, as in the case of delivery times in Pizza Business. Natural variations cause such a distribution or deviation. One of the characteristics of this distribution is that 68% of area (i.e. the data points) falls within the area of -1σ and $+1\sigma$ on either side of the mean. Similarly, 2σ on either side will cover approximately 95.5% area. 3σ on either side from mean covers almost 99.7% area. A more peaked curve (e.g. more and more deliveries were made on target) indicates lower variation or more mature and capable process. Whereas a flatter bell curve indicates higher variation or less mature or capable process. To summarize, the Sigma performance levels – One to Six Sigma are arrived at in the following way.

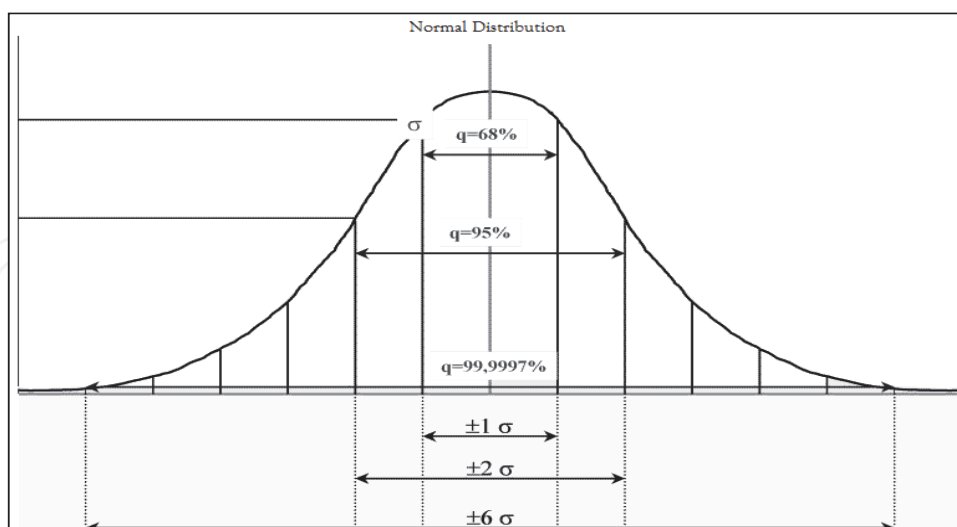


Fig. 3. Normal Distribution

If target is reached:

68% of the time, they are operating at ± 1 Sigma

95.5% of the time, they are operating at ± 2 Sigma

99.73 % of the time are operating at ± 3 Sigma

Six Sigma: 3.4 ppm = 100-99.99966%

3.4 Six sigma and TQM

Six Sigma is not just a statistical approach to measure variance; it is a process and culture to achieve excellence. Following its success, particularly in Japan, TQM seemed to be popular in organizations which preached quality as fitness for purpose, striving for zero defects with customer focus. Even though TQM was the management tool in the 1980s, by 1990s it was regarded as failure and it was written off as a concept that promised much but failed to deliver.

Research by Turner (1993) has shown that any quality initiative needs to be reinvented at regular intervals to keep the enthusiasm level high. Against this background, Six Sigma emerged to replace the 'overworked' TQM philosophy. The key success factors differentiating Six Sigma from TQM are:

1. Six Sigma emphasizes on Statistical Science and measurement.
2. Six Sigma was implemented with structured training plans at different levels (Champions, Master Belt, Black belt, and Green belt).
3. The project focussed approach with single set of Problem Solving Techniques (DMAIC).
4. The Six Sigma implementation effects are quantified in tangible savings (as opposed to TQM where the benefits cannot be measured). Quantification of tangible savings is a major selling point for Six Sigma.

3.5 Sigma quality level

Sigma Quality Level is a measure used to indicate how often the defects are likely to occur. Sigma is a mathematical term and it is the key measure of variability. It emphasizes need to control both the average and variability of a process. Table 1. shows different Sigma levels and associated defects per million opportunities. For example, Sigma level 1 indicates that it tolerates 690,000 defects per million opportunities with 31% yield. Sigma level 6 allows only 3.4 defects per million opportunities with 99.9997 yield.

Sigma Performance Levels - One to Six Sigma		
Sigma Level	Defects Per Million Opportunities	Percentage Yield
1	690,000	31
2	308,537	69
3	66,807	93.3
4	6,210	99.38
5	233	99.977
6	3.4	99.99966

Table 1. Sigma performance Levels

Before starting a Six Sigma Project, the important thing to be done first is to find the need for Six Sigma.

It is natural for Organizational processes to operate around 3 to 4 sigma level. In this section, the defect levels for some example scenarios one operating at 3 to 4 sigma level and other operating at Six Sigma level are compared. The comparisons as per Table 2. show that the defects at 3 to 4 Sigma level are found to be too high to be tolerated and organizations have to strive to achieve Six Sigma level as an obvious move. This section elaborates the need for Six Sigma with examples.

4. Why six sigma?

4.1 Does 99.9% yield is good enough for an organization?

With 99.9 % yield, we say the organization operates at 4 to 5 Sigma level. Taking into account some real world examples, with 99.9 % yield, we come across the following example scenarios which are surely unacceptable in customer's point of view :

- Unsafe drinking water almost 15 minutes each day
- 5400 arterial by pass failures each year
- Visas issued to 50 dangerous persons each year

By moving to **Six Sigma level** with 99.9997% yield, significant improvements have taken place resulting in very high quality with almost nil defects and very good customer satisfaction as shown below :

- Unsafe drinking water only few seconds a day
- 18 arterial bypass failures
- No visas issued to dangerous persons

The following real world examples explain the importance and need for achieving six sigma level quality.

Comparison of performance improvement with 99.9% and 99.9997 acceptance		
Scenarios	99.9% acceptance (Sigma Level : 4 to 5 Sigma)	99.9997 % acceptance (Sigma Level : 6 Sigma)
Arterial bypass failures in an year	5400	18
Commercial aircraft take off aborted each year	31,536	107
Train wrecks a year	180	< 1
Visa issued to dangerous persons	50	none

Table 2. Comparison of performance improvement at different sigma levels

5. Lean

5.1 Lean thinking

Lean Thinking was an another quality and productivity improvement methodology introduced in **Toyota Production Systems (TPS)** which is based on the concept of elimination of waste in processes which had resulted in *productivity gain* and *improvement of speed* and *flow* in the value stream. The principle of Lean can be stated as a relentless pursuit of the perfect process through wastage elimination in the value stream. Lean identifies three different kinds of wastes, using Japanese terminology from the Toyota Production System where lean originated: *muda* (waste of time and materials), *mura* (unevenness/variation), and *muri* (the overburdening of workers or systems).

Every employee in a lean manufacturing environment is expected to think critically about his or her job and make suggestions to eliminate waste and to participate in *kaizen*, a process of continuous improvement involving brainstorming sessions to fix problems.

5.2 Lean in a nutshell

Lean is a business transformation methodology and it is derived from the Toyota Production System (TPS). Within the Lean methodology, there is a relentless focus on

increasing customer value by reducing the cycle time of product or service delivery through the elimination of all forms of *muda* (a Japanese term for waste) and *mura* (a Japanese term unevenness in the workflow).

5.3 Six sigma in a nutshell

Six Sigma was a concept developed in 1985 by Bill Smith of Motorola, who is known as “ the Father of Six Sigma.” This concept contributed directly to Motorola’s winning of the U.S. Malcolm Baldrige National Quality Award in 1988. Six Sigma is a business transformation methodology that maximizes profits and delivers value to customers by focusing on the reduction of variation and elimination of defects by using various statistical, data-based tools and techniques.

5.4 Six sigma vs lean

Both methodologies focus on business processes and process metrics while striving to increase customer satisfaction by providing quality, on time products and services. Lean takes a more holistic view. It uses tools such as value-stream mapping, balancing of workflow, or *kanban* pull signaling systems to trigger work, streamline and improve the efficiency of processes, and increase the speed of delivery.

Six Sigma takes a more data-based and analytical approach by using tools to deliver error-free products and services, such as the following examples:

- Voice Of the Customer (VOC)
- Measurement Systems Analysis (MSA)
- Statistical hypothesis testing
- Design of Experiments (DoE)
- Failure Modes and Effects Analysis (FMEA)

Six Sigma uses an iterative five-phase method to improve existing processes. This method is known as *Define, Measure, Analyze, Improve, Control (DMAIC)*, and normally underpins Lean Six Sigma (LSS).

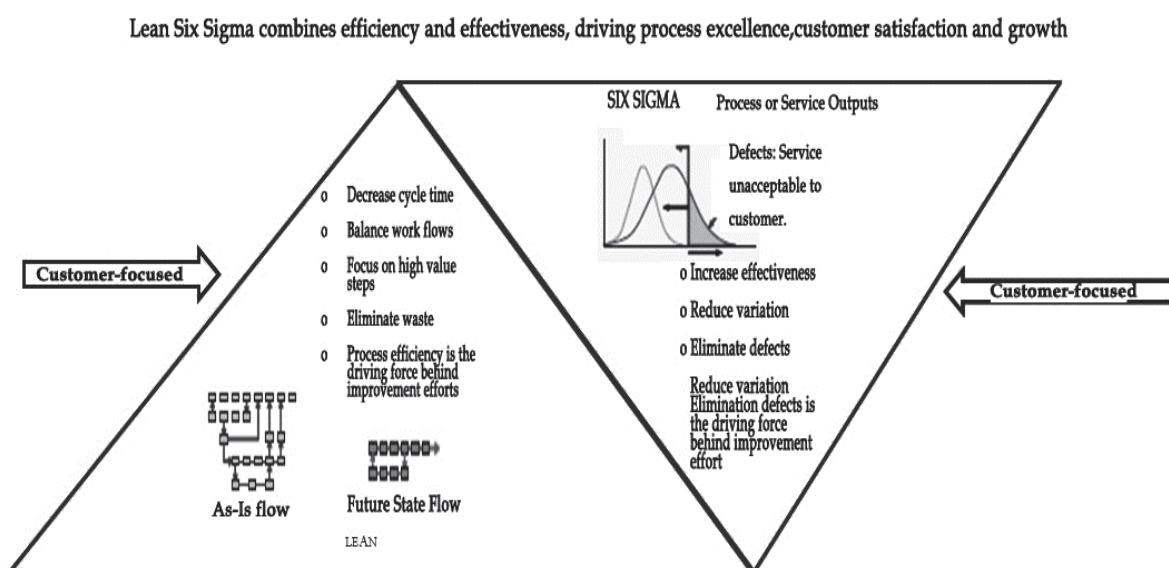


Fig. 4. Lean vs Six Sigma

Over the last 10 to 15 years, an increased need for accelerating the rate of improvement for existing processes, products, and services has led to a combination of these two approaches. As shown in Fig. 4, Lean Six Sigma combines the speed and efficiency of Lean with the effectiveness of Six Sigma to deliver a much faster transformation of the business.

6. Lean six sigma

Lean Six Sigma came into existence which is the combination of Lean and Six Sigma.

The fusion of Lean and Six Sigma is required because :

- Lean cannot bring process under statistical control, and
- Six Sigma alone cannot dramatically improve process speed or reduce invested capital.

Lean Six Sigma is a disciplined methodology which is rigorous, data driven, result-oriented approach to process improvement. It combines two industry recognized methodologies evolved at Motorola, GE, Toyota, and Xerox to name a few. By integrating tools and processes of Lean and Six Sigma, we're creating a powerful engine for improving quality, efficiency, and speed in every aspect of business.

Cindy Jutras, Vice President, Research Fellow and Group Director *Enterprise Applications Aberdeen Group* says, "Lean and Six Sigma are initiatives that were born from the pursuit of operational excellence within manufacturing companies. While Lean serves to eliminate waste, Six Sigma reduces process variability in striving for perfection. When combined, the result is a methodology that serves to improve processes, eliminate product or process defects and to reduce cycle times and accelerate processes".

Embedding a rigorous methodology like lean six sigma into organizational culture is not a short journey, but it is a deep commitment not only to near-term results but also a long-term, continuous, even break-through results.

7. Six sigma DMAIC methodology

Motorola developed a five phase approach called 'DMAIC Model' to achieve the highest level in the Six Sigma, i.e., 3.4 defects per million. The five phases are:

- **Define** process goals in terms of key critical parameters (i.e. critical to quality or critical to production) on the basis of customer requirements or Voice Of Customer (VOC)
- **Measure** the current process performance in context of goals
- **Analyze** the current scenario in terms of causes of variations and defects
- **Improve** the process by systematically reducing variation and eliminating defects
- **Control** future performance of the process

Table 3 lists the important deliverables and tools used in each step of 'DMAIC Model'. The subsequent sections brief the process involved in each phase.

7.1 Define

In the Define phase of the project, the focus is on defining the current state by making the *Problem statement* which specifies what the team wants to improve upon which illustrates the need for the project and potential benefit. The type of things that are determined in this phase include the *Scope of the project*, the *Project Charter*.

7.1.1 Project charter

The problem statement and goal statement are the part of Project Charter. The following deliverables should be part of the project charter :

- Business Case (Financial Impact)
- Problem statement
- Project Scope (Boundaries)
- Goal Statement
- Role of team members
- Mile Stones/ deliverables (end products of the project)
- Resources requiered

Strategic Steps	Deliverables	Tools used
Define	Project Charter or Statement of Work(SoW)	Gantt Chart/Time Line Flow Chart/Process Map Quality Function Deployment (QFD)
Measure	Base Line figures	SIPOC (Suppliers, Inputs, Process, Outputs, and Customers) or IPO (Input-Process-Output) diagram
Analyze	Identified Root Causes	Cause-and-Effect Diagram 5-Why Scatter Diagram Regression ANOVA
Improve	Selected root causes and counter measures Improvement Implementation Plan	Affinity Diagram Hypothesis Testing DoE Failure Mode Effect Analysis (FMEA)
Control	Control Plan Charts & Monitor Standard Operating Procedures (SOP) Corrective Actions	Control Charts Poka-Yokes Standardization Documentation Final Report Presentation

Table 3. DMAIC Methodology

The metrics to be used are developed at this phase. The basic metrics are cycle time, cost, value, and labor. Some of the methods used for identifying the metrics are Pareto diagram, SIPOC, voice of the customer, affinity diagram, critical to quality tree.

SIPOC stands for Suppliers, Inputs, Process, Outputs, and Customers. This approach helps us to identify characteristics that are key to the process which in term facilitates identifying appropriate metrics to be used to effect improvement.

To create a SIPOC diagram:

- Identify key process activities
- Identify outputs of the process and known customers
- Identify inputs to the process and likely suppliers

Fig. 5 shows an example SIPOC Diagram of Husband making wife a cup of tea. A SIPOC diagram is a tool that is used to gather a snapshot view of process information. SIPOC diagrams are very useful at the start of a project to provide information to the project team before work commences.

An IPO (Input-Process-Output) diagram is a visual representation of a process or activity as shown in Table 4. It lists input variables and output characteristics. It is useful in defining a process and recognizing the input variables and responses or outputs. It helps us to understand what inputs are needed to achieve each specific output.

Input	Process	Output
Centigrade	Prompt for centigrade value	fahrenheit
	Compute fahrenheit value	

Table. 4 An IPO diagram

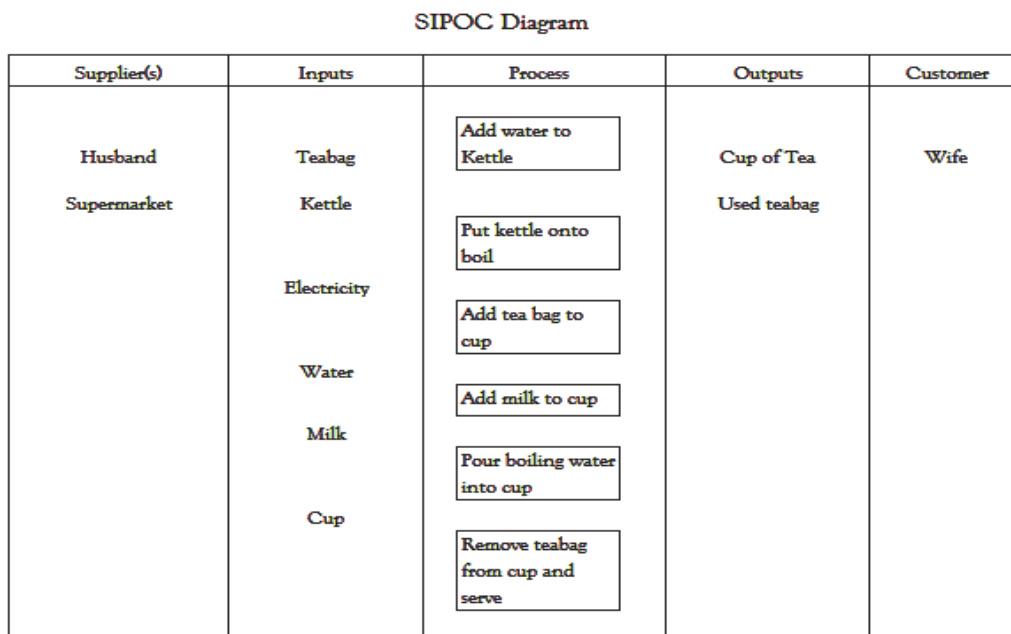


Fig. 5. SIPOC Diagram

7.2 Measure

The Measure is the second step of the Six Sigma methodology. A base line measure is taken using actual data. This measure becomes the origin from which the team can gauge improvement.

It is within the Measure phase that a project begin to take shape and much of the hands-on activity is performed. The goal of Measure phase is to establish a clear understanding of the current state of the process you want to improve. For example, a medical practioner prescribes various tests like blood test, ECG test etc for a patient admitted in a hospital. The test reports of various laboratorial tests reflect the current state of health of the patient. Similarly, a Six Sigma practioner, determines current state of health of the system under consideration in this phase.

The deliverables in this phase are refined process map, and refined Project Charter. Some of the tools used in Measure phase are :

- Flow Charts

- Fish bone diagrams
- Descriptive Statistics
- Scatter diagrams
- Stem and Leaf plots
- Histograms

These metrics will establish the base line of the current state. The outcome of applying these tools in the form of charts, graphs or plots helps the Six Sigma Practitioner to understand how the data is distributed. He or she is able to know what the data are doing. The distribution that is associated with data related to a process speaks volumes. The data distribution can be categorized into:

- Normal distribution
- Weibul
- Poison
- Hypergeometric
- Chi Square

The data can be continuous or discrete.

7.3 Analyze

In this step, the team identify several possible causes (X's) of variation or defects that are affecting the outputs (Y's) of the process. One of the most frequently used tools in the analyze phase is the 'Cause and Effect Diagram'. The Cause & Effect Diagram is a technique to graphically identify and organize many possible causes of a problem (effect). They help identify the most likely ROOT CAUSES of a problem. This tool can help focus problem solving and reduce subjective decision making. Fig. 6 illustrates a cause and effect diagram which helps to find out possible causes for software not being reliable. Root cause is the number one team deliverable coming out of the analysis step. Causes can be validated using new or existing data and applicable statistical tools such as scatter plots, hypotheses testing, ANOVA, regression or Design of Experiments. Some of the tools used in root cause analysis are shown in Fig. 7.

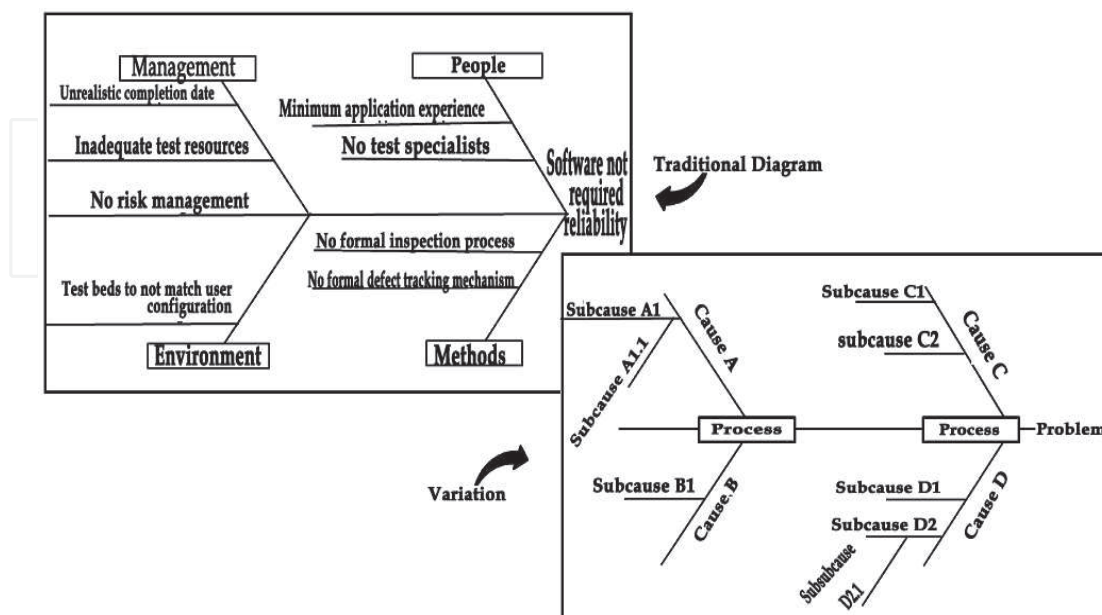


Fig. 6. Cause and Effect Diagram

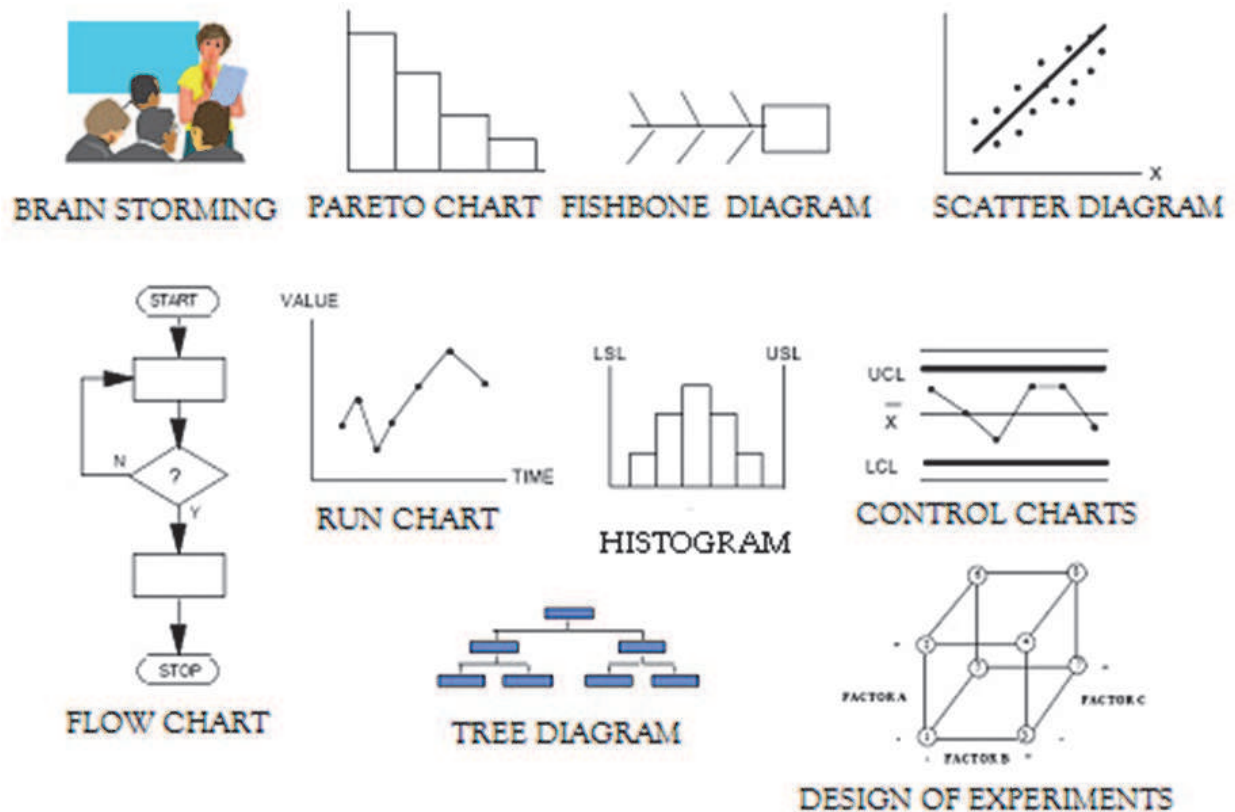


Fig. 7. Tools used in Root cause analysis

7.4 Improve

In this step, the team would brainstorm to come up with counter measures and lasting process improvements that address the validated root causes. The most preferred tool used in this phase is affinity diagram.

We have measured our data and performed some analysis on the data to know where our process is, it is time to improve it.

One of the important methods used for improvement of a process is Design of Experiments (DoE).

7.4.1 Affinity diagram

A pool of ideas, generated from a brainstorming session, needs to be analyzed, prioritized before they can be implemented. A smaller set of ideas are easy to sift through and evaluate without applying any formal technique. Affinity diagramming is an effective technique to handle a large number of ideas. It is typically used when

1. Large data set is to be traversed, like ideas generated from brainstorming and sieve for prioritization.
2. Complexity due to diverse views and opinions.
3. Group involvement and consensus. The process of affinity diagramming requires the team to categorize the ideas based on their subject knowledge thereby making it easy to sift and prioritize ideas. Fig. 8 shows an example affinity diagram with prioritized ideas categorized into different headings.

7.4.2 Design of experiments (DoE)

With DoE, you look at multiple levels of multiple factors simultaneously and make decisions as to what levels of the factor will optimize your output.

- A statistics-based approach to designed experiments
- A methodology to achieve a predictive knowledge of a complex, multi-variable process with the fewest trials possible
- An optimization of the experimental process itself

7.5 Control

In this step, our process has been measured, our data analyzed, and our process improved. The improvement we have made will be sustained. We need to build an appropriate level of control so that it does not enter into an undesirable state. One of the important tool that can be used to achieve this objective is Statistical Process Control (SPC). The purpose of SPC is to provide the practitioner with real-time feedback which indicates whether a process is under control or not.

There are also some lean tools like the 5S's, the Kaizen blitz, kanban, poka-yoke etc.

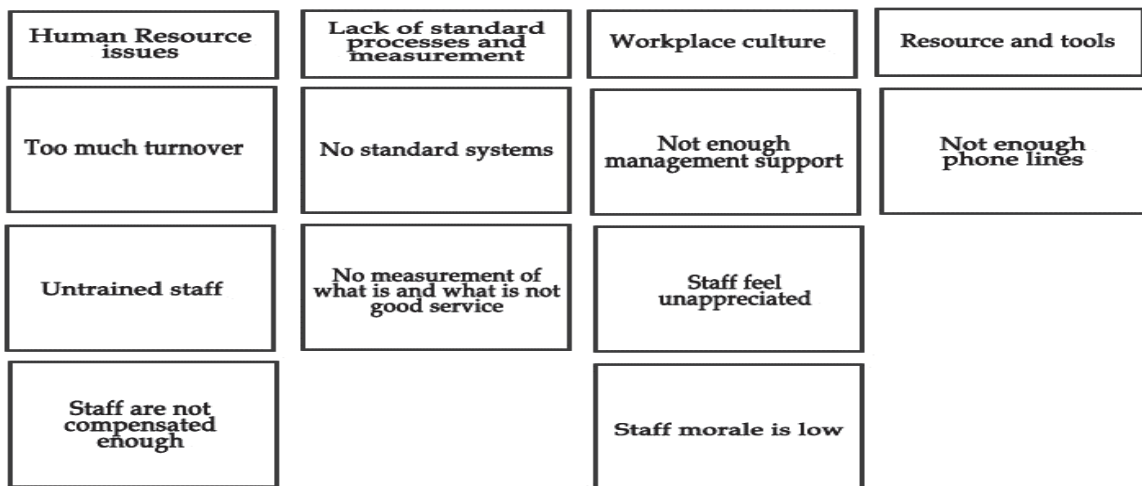


Fig. 8. Affinity Diagram

Six Sigma Tools	Advanced Tools
Pareto Analysis Flow Process Chart Upper Control Limit (UCL) / Lower Control Limit (LCL) Control Chart Cause and Effect Diagram Input-Process-Output Diagrams Brain Storming Scatter Diagram Histogram The Seven Wastes The Five Ss	Failure Mode Effect Analysis (FMEA) Design of Experiments (DoE) Design For Six Sigma (DFSS)

Table 5. Six Sigma Tools

8. Six sigma and lean tools

Table 5. summarizes some of the important Six Sigma tools used for easy reference. Pareto analysis, Control charts and Failure Mode Effect Analysis are explained in detail with examples.

8.1 Pareto Analysis

Pareto Analysis is a statistical technique in decision making that is used for the selection of a limited number of tasks that produce significant overall effect. It uses the Pareto Principle (also known as the 80/20 rule) the idea that a large majority of problems (80%) are produced by a few key causes (20%). This is also known as the vital few and the trivial many. The 80/20 rule can be applied to almost anything:

- 80% of customer complaints arise from 20% of your products or services.
- 80% of delays in schedule arise from 20% of the possible causes of the delays.
- 20% of your products or services account for 80% of your profit.
- 20% of your sales-force produces 80% of your company revenues.
- 20% of a systems defects cause 80% of its problems.

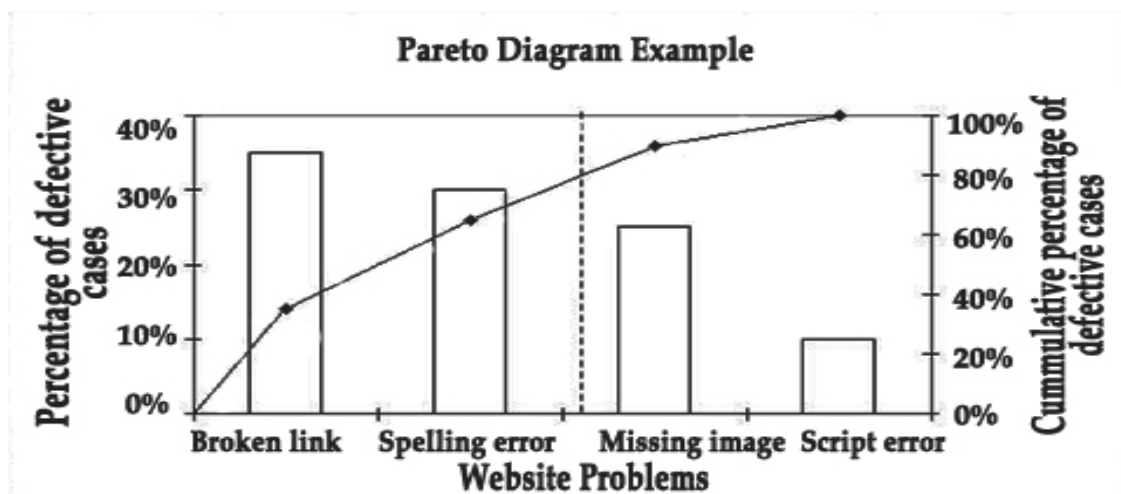


Fig. 9. Pareto diagram

The Pareto Principle has many applications in quality control. It is the basis for the Pareto diagram, one of the key tools used in total quality control and Six Sigma. Seven steps to identifying the important causes using Pareto Analysis :

1. Form a table listing the causes and their frequency as a percentage.
2. Arrange the rows in the decreasing order of importance of the causes, i.e. the most important cause first.
3. Add a cumulative percentage column to the table.
4. Plot with causes on x-axis and cumulative percentage on y-axis.
5. Join the above points to form a curve.
6. Plot (on the same graph) a bar graph with causes on x-axis and percent frequency on y-axis.
7. Draw a line at 80% on y-axis parallel to x-axis. Then drop the line at the point of intersection with the curve on x-axis. This point on the x-axis separates the important causes on the left and less important causes on the right.

8.2 Control charts

A control chart is a statistical tool used to distinguish between variation in a process resulting from common causes and variation resulting from special causes. It presents a graphic display of process stability or instability over time as shown in Fig. 10. Every process has variation. Some variation may be the result of causes which are not normally present in the process. This could be special cause variation. Some variation is simply the result of numerous, ever-present differences in the process. This is common cause variation. Control Charts differentiate between these two types of variation. One goal of using a Control Chart is to achieve and maintain process stability.

Process stability is defined as a state in which a process has displayed a certain degree of consistency in the past and is expected to continue to do so in the future. This consistency is characterized by a stream of data falling within control limits based on plus or minus 3 standard deviations (3 sigma) of the centerline.

A stable process is one that is consistent over time with respect to the center and the spread of the data. Control Charts help you monitor the behavior of your process to determine whether it is stable. Like Run Charts, they display data in the time sequence in which they occurred. However, Control Charts are more efficient than Run Charts in assessing and achieving process stability. Your team will benefit from using a Control Chart when you want to monitor process variation over time.

1. Differentiate between special cause and common cause variation.
2. Assess the effectiveness of changes to improve a process.
3. Communicate how a process performed during a specific period.

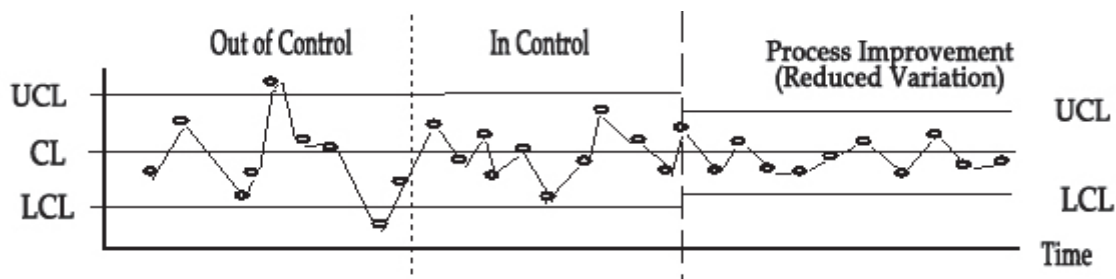


Fig. 10. Control Charts

8.3 Failure mode and effects analysis (FMEA)

Failure Mode and Effects Analysis (FMEA) is a model used to prioritize potential defects based on their severity, expected frequency, and likelihood of detection. An FMEA can be performed on a design or a process, and is used to prompt actions to improve design or process robustness. The FMEA highlights weaknesses in the current design or process in terms of the customer, and is an excellent vehicle to prioritize and organize continuous improvement efforts on areas which offer the greatest return.

The next step is to assign a value on a 1-10 scale for the severity, probability of occurrence, and probability of detection for each of the potential failure modes. After assigning a value, the three numbers for each failure mode are multiplied together to yield a Risk Priority Number (RPN). The RPN becomes a priority value to rank the failure modes, with the highest number demanding the most urgent improvement activity. Error-proofing, or poka-yoke actions are often an effective response to high RPN's.

Following is an example of a simplified FMEA for a seat belt installation process at an automobile assembly plant.

FAILURE MODE & EFFECTS ANALYSIS (FMEA)				Date: 01/01/2011
Process Name: Left Front Seat Belt Install		Process Number: SBT 145		Revision: 1.3
Failure Mode	A) Severity Rate 1-10 10=Most Severe	B) Probability of Occurance Rate 1-10 10=Highest Probability	C) Probability of Detection Rate 1-10 10=Lowest Probability	Risk Preference Number (RPN) AxBxC
1) Select Wrong Color Seat Belt	5	4	3	60
2) Seat Belt Bolt not tightened	9	2	8	144
3) Trim Cover Clip Misaligned	2	3	4	24

Fig. 11. FMEA

As you can see, three potential failure modes have been identified. Failure mode number two has an RPN of 144, and is therefore the highest priority for process improvement. FMEA's are often completed as part of a new product launch process.

RPN minimum targets may be established to ensure a given level of process capability before shipping product to customers. In that event, it is wise to establish guidelines for assessing the values for Severity, Occurrence, and Detection to make the RPN as objective as possible.

9. Case studies on lean six sigma

Having seen Six Sigma Methodology and Lean Six Sigma tools elaborately, it is appropriate to look into some case studies on Six Sigma implementations. We present two case studies on Six Sigma implementation by two leading companies in this section. These studies reinforce Lean and Six Sigma Concepts as well as demonstrate the the tools used by them for implementing the same. The importance of achieving operational excellence by way of reducing defects and variations in processes as well as eliminations of non value adding steps in processes can be inferred from these case studies . One more case study on "Mumbai Dabba walahs" also presented at the end of the chapter to clearly demonstrate that Six Sigma is a tool not only for coporates but also it is for common man who are capable of achieving Six Sigma level in their services in execution of their daily tasks by fulfilling their customer needs.

9.1 Honeywell aerospace electronics system, singapore – implementing six sigma quality

Honeywell is a US\$ 254 billion diversified technology and manufacturing leader, serving customers worldwide with aerospace products and services One of its business units, Aerospace Electronics System in Singapore, uses Six Sigma as a best practice to improve processes in most of its operations. The organisation, which has 150 employees, was set up in Singapore in 1983. It manufactures high quality avionics and navigation equipment and systems. Its principal customers include Cessna, Bell Helicopters, Raytheon, Learjet, Mooney Aircraft, Piper Aircraft, FedEx and Singapore Aerospace.

Six Sigma *Plus* is Honeywell's overall strategy to accelerate improvement in all processes, products and services, and to reduce the cost of poor quality by eliminating waste and reducing defects and variations. Six Sigma is already understood worldwide as a measure of excellence. The "*Plus*" is derived from Honeywell's Quality Value assessment process and expanded former AlliedSignal's Six Sigma strategic tools.

The strategy requires that the organisation approach every improvement project with the same logical method of DMAIC:

- Define the customer critical parameters
- Measure how the process performs
- Analyse causes of problems
- Improve the process to reduce defects and variations
- Control the process to ensure continued, improved performance

9.1.1 Implementing six sigma plus

The tools and skills that help in the implementation of the DMAIC method include:

- Process mapping which helps to identify the order of events in producing a product or service and compares the "ideal" work flow to what actually happens.
- Failure mode and effect analysis which helps to identify likely process failures and minimises their frequency.
- Measurement system evaluation which helps in the assessment of measurement instruments to enable the better separation of important process variations from measurement "noise".
- Statistical tests which assist in the separation of significant effects of variable from random variation.
- Design of experiments which is used to identify and confirm cause and effect relationships.
- Control plans which allow for the monitoring and controlling of processes to maintain the gains that have been made.
- Quality function deployment which is a tool for defining what is important to customers; it enables better anticipation and understanding of customer needs.
- Activity based management to look at product and process costs in a comprehensive and realistic way by examining the activities that create the costs in the first place and hence allowing for better subsequent management.
- Enterprise resource planning which uses special computer software to integrate, accelerate and sustain seamless process improvements throughout an organisation.
- Lean enterprise with skills to enhance the understanding of actions essential to achieving customer satisfaction. These skills simplify and improve work flow, help eliminate unnecessary tasks and reduce waste throughout a process.

9.1.2 Impact of six sigma plus

In the past, generic and low-end competencies such as the manufacture of printed circuit boards were outsourced. With Six Sigma *Plus*, core competencies were redefined and control plans established.

Presently, Aerospace Electronics System, Singapore focuses on core competencies that are unique to itself, such as final assembly and test and final alignment. This helped to stabilise the workforce for the organisation, which once experienced high turnover for its front-end and low-skill jobs. Waste has also been reduced from key business processes. For example,

inspection, which is considered as non-value added, has been eliminated. Instead, Reliance on Operators' Inspection (ROI) is practised and this has helped to increase the value added per employee.

In the past, all Honeywell Singapore's products were 100% inspected by a team from the US. Currently, the Federal Aviation Agency (FAA) certifies its products for manufacturing in Singapore; and 100% of its products are shipped direct to stock to Kansas, US, saving \$1 million in inspection cost. In addition, audits by FAA involve only observations and not all processes need to be audited. This is achieved by ensuring that the necessary quality procedures are built into the process. Six Sigma *Plus* in Honeywell has led to the following results:

- Increased Rolled Throughput Yield (RTY)
- Reduced variations in all processes
- Reduced cost of poor quality (COPQ)
- Deployment of skilled resources as change agents.

9.1.3 Key learning points

Some of the key learning points are:

- Strong management commitment and support.
- Well-structured approach and deployment process
- Team-based approach.
- Sharing Six Sigma Plus knowledge.

9.2 Lean six sigma in higher education: applying proven methodologies to improve quality, remove waste, and quantity opportunities in college and universities

9.2.1 Lean flow today

This is another case study which highlights the experiences of Ms Xerox Corporation in implementing Six Sigma in higher education. The case study starts with discussion on the importance of Lean Principles and then elaborately discuss Six Sigma implementation strategies. While Lean Flow began as a manufacturing model, today's definition has been extended to include the process of creating an "optimized flow" anywhere in an organization. The only requirement is that this "flow" challenge current business practices to create a faster, cheaper, less variable, and error prone process. Lean Flow experts have found that the greatest success can be achieved by methodically seeking out inefficiencies and replacing them with "leaner", more streamlined processes. Sources of waste commonly plaguing most business processes include:

- Waste of worker movement (unnecessary steps)
- Waste of making defective products
- Waste of over production
- Waste in transportation
- Waste of processing
- Waste of time (idle)
- Waste of stock on hand

9.2.2 Putting lean flow to work

Implementing a Lean Flow requires having the right data and knowing how to use it. There are a number of different approaches taken by organizations, but fundamentally, Lean Flow is achieved by:

- Analyzing the steps of a process and determining which steps add value and which do not.
- Calculating the costs associated with removing non-value-added steps and comparing those costs versus expected benefits.
- Determining the resources required to support

9.2.3 Six sigma today

While the concept of Six Sigma began in the manufacturing arena decades ago, the idea that organizations can improve quality levels and work “defect-free” is currently being incorporated by higher education institutions of all types and sizes. So what is today’s definition of Six Sigma? It depends on whom you ask. In his book *Six Sigma: SPC and TQM in Manufacturing and Services*, Geoff Tennant explains that “Six Sigma is many things... a vision; a philosophy; a symbol; a metric; a goal; a methodology.” Naturally, as Six Sigma permeates into today’s complex, sophisticated higher education landscape, the methodology is “tweaked” to satisfy unique needs of individual schools. But no matter how it is deployed, there is an overall framework that drives Six Sigma toward improving performance. Common Six Sigma traits include:

- A process of improving quality by gathering data, understanding and controlling variation, and improving predictability of a school’s business processes.
- A formalized Define, Measure, Analyze, Improve, Control (DMAIC) process that is the blueprint for Six Sigma improvements.
- A strong emphasis on value. Six Sigma projects focus on high return areas where the greatest benefits can be gained.
- Internal cultural change, beginning with support from administrators and champions. value-added steps while eliminating non-value added steps.
- Taking action.

Lean Six Sigma is the application of lean techniques to increase speed and reduce waste, while employing Six Sigma processes to improve quality and focus on the Voice of the Customer. Lean Six Sigma means doing things right the first time, only doing the things that generate value, and doing it all quickly and efficiently.

Xerox Global Services imaging and repository services leverage the Lean Six Sigma-based DMAIC approach:

Define

The Define phase of the DMAIC process is often skipped or short-changed, but is vital to the overall success of any Lean Six Sigma project. This is the phase where the current state, problem statement, and desired future state are determined and documented via the Project Charter. Xerox asks questions like: *What problem are we trying to solve? What are the expected results if we solve the problem? How will we know if the problem is solved? How will success be measured?* In most cases where imaging and repository services are involved, the problem relates to document management and access. Schools look to improve the ways documents are created, stored, accessed, and shared so they may accelerate and enhance work processes, share information more conveniently, and collaborate more effectively. As the project progresses and more information is collected in future phases, the problem statement developed in the Define phase is refined.

Measure

The Measure phase is where Xerox gathers quantitative and qualitative data to get a clear view of the current state. This serves as a baseline to evaluate potential solutions and

typically involves interviews with process owners, mapping of key business processes, and gathering data relating to current performance (time, volume, frequency, impact, etc.).

Analyze

In the Analyze phase, Xerox studies the information gathered in the Measure phase, pinpoints bottlenecks, and identifies improvement opportunities where non-value-add tasks can be removed. A business case is conducted, which takes into account not only hard costs but also intangible benefits that can be gained, such as user productivity and satisfaction, to determine if the improvement is cost-effective and worthwhile. Finally, the Analyze phase is when technological recommendations are provided.

Improve

The Improve phase is when recommended solutions are implemented. A project plan is developed and put into action, beginning with a pilot program and culminating in full-scale, enterprise-wide deployment. Where appropriate, new technology is implemented, workflows are streamlined, paper-based processes are eliminated, and consulting services are initiated. Key factors of success during this phase are acceptance by end users and enterprise-wide change without any degradation of current productivity levels.

Control

Once a solution is implemented, the next step is to place the necessary “controls” to assure improvements are maintained long-term. This involves monitoring—and in many cases, publicizing—the key process metrics to promote continuous improvement and to guard against regression. In many cases, Xerox will revisit the implementation after 3-6 months to review key metrics and evaluate if the initial progress has been sustained. A common practice is to put key metrics, including hard cost savings and achievement of pre-defined Service Level Agreements, in full view “on the dashboard” to provide continuous feedback to the organization and so decision-makers can assess the project’s level of success as it moves forward.

9.3 Dabbawalas and six sigma

A Six Sigma practioner need not be an educated individual. One interesting case study quoted for Six Sigma application is dabbawalas of Mumbai, India. Dabbawallas (also known as Tiffinwallahs) are persons employed in a service industry in Mumbai whose primary job is collecting the freshly cooked food in lunch boxes from the residences of office workers (mostly in the suburbs), delivering it to their respective work places and returning the empty boxes to the customer’s residence by using various modes of transport. Around 5000 dabbawalas in Mumbai transport around 200,000 lunch boxes every day. The reliability of their services meet Six Sigma standard as per study by Forbes Magazine in the year 2002. It has been found that they make less than one mistake in every 6 million deliveries. The tiffin boxes are correctly delivered to their respective destinations as the dabbawalls use an unique identifying coding scheme inscribed on the top of each tiffin box.

10. Conclusion

Six Sigma was a concept developed in 1985 by Bill Smith of Motorola.

Six Sigma is a business transformation methodology that maximizes profits and delivers value to customers by focusing on the reduction of variation and elimination of defects by using various statistical, data-based tools and techniques.

Lean is a business transformation methodology which was derived from the Toyota Production System (TPS) which focusses on increasing customer value by reducing the cycle time of product or service delivery through the elimination of all forms of waste and unevenness in the workflow.

Lean Six Sigma is a disciplined methodology which is rigorous, data driven, result-oriented approach to process improvement. It combines two industry recognized methodologies evolved at Motorola, GE, Toyota, and Xerox to name a few. By integrating tools and processes of Lean and Six Sigma, we're creating a powerful engine for improving quality, efficiency, and speed in every aspect of business.

Lean and Six Sigma are initiatives that were born from the pursuit of operational excellence within manufacturing companies. While Lean serves to eliminate waste, Six Sigma reduces process variability in striving for perfection. When combined, the result is a methodology that serves to improve processes, eliminate product or process defects and to reduce cycle times and accelerate processes

Lean and Six Sigma are conceptually sound technically fool proof methodologies and is here to stay and deliver break through results for a long time to come.

This chapter discussed the history of Six Sigma and Lean thinking and important steps in implementing Lean Six Sigma like DMAIC methodology. Some of the important Six Sigma and Lean tools were discussed with examples which will be of help to a Six Sigma practitioner. Three case studies were presented which shares experiences on how Six Sigma implementation had helped them to improve their bottom line by removing variations in the processes and eliminating defects and reducing cycle time.

11. Acknowledgment

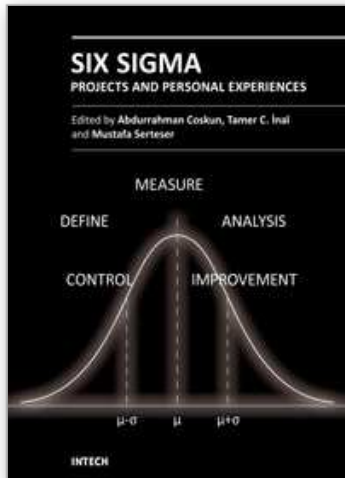
We have presented two case studies on Six Sigma implementation by Ms. Honeywell International Inc and Xerox Global Services we sincerely acknowledge for their pioneering work on quality improvement measures by them for improving bottom line of their operations. Some of the illustrations and charts related to Six Sigma and lean tools presented are taken from internet resources available online and the authors acknowledge and thank the contributors.

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In the new millennium the increasing expectation of customers and products complexity has forced companies to find new solutions and better alternatives to improve the quality of their products. Lean and Six Sigma methodology provides the best solutions to many problems and can be used as an accelerator in industry, business and even health care sectors. Due to its flexible nature, the Lean and Six Sigma methodology was rapidly adopted by many top and even small companies. This book provides the necessary guidance for selecting, performing and evaluating various procedures of Lean and Six Sigma. In the book you will find personal experiences in the field of Lean and Six Sigma projects in business, industry and health sectors.

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