Six Sigma Quality: Concepts & Cases- Volume I

STATISTICAL TOOLS IN SIX SIGMA DMAIC PROCESS WITH MINITAB® APPLICATIONS

Chapter 1

Introduction to Six Sigma, Lean Six Sigma & Design for Six Sigma (DFSS)

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Summary

What Is Six Sigma?

Six Sigma is a business strategy that employs well-structured continuous improvement methodology and statistical tools to reduce defects and process variability. It is a quality discipline that focuses on product and service excellence. Six Sigma has been employed in numerous companies to reduce operating cost, increase sales and revenue, increase reliability, incorporate innovation in products and services, increase productivity and profitability. The objective of a Six Sigma program is to reduce the variation in the process to the extent that the likelihood of producing a defect is virtually non-existent. This means improving quality, and meeting or exceeding customers' expectations. The improved quality and reliability in products and services leads to higher perceived value and increased market share thereby; increasing revenue and profitability. The term *sigma* (denoted by the Greek letter, σ) is a metric based on the statistical measure called *standard deviation* and is a measure of variability within a given population around the mean. In Six Sigma a *metric* is a measurement of certain quality characteristics for example; percent defect. The term *sigma* also refers to the population that falls within plus or minus six standard deviations of the mean. Statistically, Six Sigma equates to 3.4 defects per million opportunities. Thus, a Six Sigma process is capable of producing 3.4 defects per million opportunities (DPMO). In practice, this refers to the maximum acceptable range of noncompliance.

Six Sigma seeks to find and eliminate causes of defects and errors in manufacturing and service processes by focusing on outputs that are critical to customers and a clear financial return for the organization. Six Sigma can be viewed as:

- a customer focused approach to create near perfect processes, products, and services all aligned to delivering what the customer wants.
- a project based approach where majority of projects are selected for measurable bottom line or customer impact.
- a methodology that uses well defined set of statistical tools and process improvement techniques by well trained people in an organization.
- a business strategy that has evolved from a focus on process improvement using statistical tools to a comprehensive framework for managing a business

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Business Success of Six Sigma

More and more companies are realizing that it is possible to achieve dramatic improvements in cost, quality, and time using Six Sigma. Several companies including Toyota, General Electric, and Motorola have accomplished impressive results with Six Sigma. The concept of Six Sigma originated in Motorola in the later part of the 1980s. Since then many companies – including banks and hospitals – have successfully implemented Six Sigma programs within their corporate structure. Among the companies who have reported significant success with Six Sigma are Texas Instruments, Honeywell, Boeing, IBM, Caterpillar, 3M, Xerox, Raytheon, Citibank, Home Depot, and the U. S. Air Force. The list goes on. Six Sigma has been successfully applied to many service industries including health care and financial services companies. The savings resulting from Six Sigma initiative range from $150 million to $800 million for some of the big companies.

Based on the industry research and current trend; Six Sigma and related methodologies are considered as one of the most sought after emerging technologies and programs by industries today. A current industry survey of 600 companies shows that approximately 41% are implementing Six Sigma, and the vast majority of them (approximately 87%) are implementing Lean Six Sigma and related technologies [World Class Manufacturing Report, 2005][45]. The survey also shows that 72% of the companies acknowledge that Six Sigma and related technologies have increased their profitability [Quality Digest][36].

A recent survey conducted in 2010 by the consulting firm Compdata indicates that the deployment of Lean and Six Sigma methods remains strong in the manufacturing sector. The section of the survey on safety and cost-cutting procedures showed that nearly 70 percent of the 1,100 companies surveyed have implemented Lean practices in their operations. The survey also found that 58.6 percent of the companies are using Six Sigma, which is almost unchanged from the 58.5 percent who reported the same in 2009.

A survey by *Quality Digest*[36] on Six Sigma shows some interesting facts. Approximately 2,577 quality professionals took part in the survey. This survey reports: "In the two years we have been tracking Six Sigma usage and perceptions, the predominant finding of survey responses is the overwhelming agreement on this methodology as a means to drastically reduce waste and improve productivity. Six Sigma practitioners are a zealous lot, and with good reason; when properly implemented and supported by management, the process yields huge results. Very few of those who utilize Six Sigma methodologies have anything negative to say about it." The reported down side was the difficulty of implementing it within small companies. The following are the testimonials on Six Sigma from companies with fewer than 500 employees:

- Our overall cost of quality system failure was less than 0.5% of sales. We were benchmarked as the top quality supplier for 90% of our customers.
- Reduced machine cycle time by 20%, scrap reduction by 25%, increased production rate by 15%.
- Waste reduction saves $340,000 annually at one facility.
- Various projects--$5,000 to $1.2 million.
- Overall business results--$250,000 annually.
- Waste reduction saves $15,000 per month. Customer satisfaction increased from 10% to 91% within three months.
- We utilized lean to re-create the entire factory, building a new plant. Then we went into the plant that was fairly well run and pulled out another $271,000, representing about 23% of net revenues for that year.

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Current Trends

The following are some impressive data reported in iSixSigma LLC website (http://www.isixsigma.com/research). The research report states:

- Over the past 20 years, use of Six Sigma, the popular business improvement methodology, has saved Fortune 500 companies an estimated $427 billion, according to research published in the January/February 2007 issue of iSixSigma Magazine.
- Corporate-wide Six Sigma deployments save an average 2 percent of total revenue per year.
- Six Sigma adoption has increased phenomenally in recent years.
- Six Sigma started out slowly in the late 1980s but then took off in the mid-1990s once people started seeing successes at companies like GE and AlliedSignal.
- About 53 percent of Fortune 500 companies are currently using Six Sigma and that figure rises to 82 percent when you look at just the Fortune 100.
- The market for Six Sigma training and consulting is very much open where 47 percent of the Fortune 500 have not yet embraced the methodology.
- Six Sigma has a 20-year record of accomplishment of impressive results and is still expanding.

Statistical Basis of Six Sigma

One of the major objectives of a Six Sigma program is to reduce variation in products and processes. The process variation is reduced to an extent that a spread of 12-Sigmas (6-Sigmas on either side of the mean) fits within the process specifications. The specification limits (also called tolerance) are established during the design phase of the product or process, or the customer provides them. A Six Sigma quality level represents 3.4 defects per million opportunities. This means that if a process is operating at a Six Sigma level, it will produce no more than 3.4 defects per million.

This is only possible when the variation in the process is reduced significantly. To be exact, to achieve a Six Sigma process, the variation must be reduced to half or 50% that of a three sigma level quality. With the variation reduced to this level, even a drift in the process on either side of the mean or target value will not allow the process to go out of control. It is important to note here that no process can be controlled exactly at the target or the mean value. It is natural for a process to drift from its mean or target value in due course. This drift or shift can be as much as 1.5 standard deviations on either side of the mean or the target. In a Six Sigma process, the process variation is equal to half of the design specification or tolerance so that a shift of as much as 1.5 standard deviations on either side of the target will keep the process well within the tolerance, and the likelihood of producing non-conforming products is virtually non-existent.

Figure 1.1 compares a 3-Sigma process to a 6-Sigma process. In a 3-Sigma process, 6-Sigmas (or 3-Sigmas on either side of the mean) fit within the specification limits whereas; in a 6-Sigma process, 12-Sigmas (or 6-Sigmas on either side of the mean) fit within the specification limits.

In a 3-Sigma process where three standard deviations just fit within the specification limits, the process will begin producing nonconforming products if there is a shift in the process mean. This process is very sensitive to the process shift.

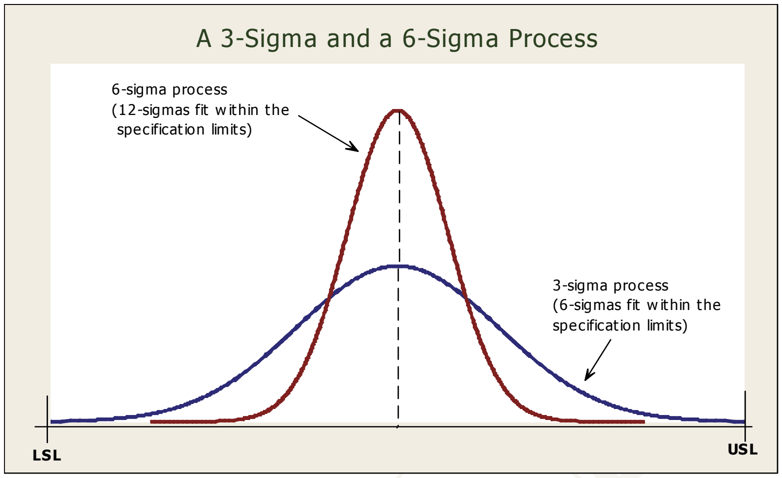

Figure 1.1: Comparing a 3-Sigma Process to a 6-Sigma Process

In a Six Sigma process, even if the process mean shifts by as much as 1.5-Sigma on either side of the mean, the majority of the products will remain within specification limits. In fact, in a Six Sigma process, a shift in the process mean of 1.5-Sigma on either side of the mean results in 3.4 nonconforming products per million. This is demonstrated below using a sample calculation. Figure 1.2 shows a Six Sigma process where 12 standard deviations 6-Sigmas on either side of the mean) fit within thespecification limits. It also shows the shift in the process mean by as much as $\pm 1.5\,\sigma$.

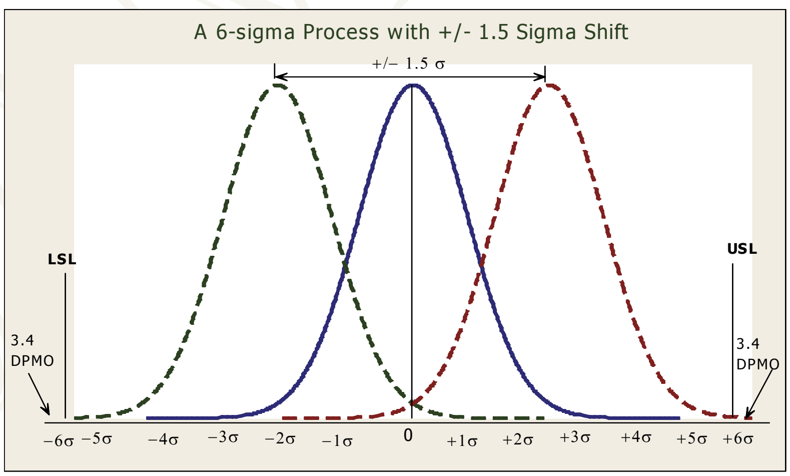

Figure 1.2: A Six Sigma Proces

Table 2.2 shows the nonconforming parts per million for different sigma processes or sigma quality level.

Table 2.2: Percent Nonconforming for a Non-centered Process
(A Process Mean Shift of ±1.5σ)

Specification Limits	Percent Within Specification Limits	Percent Outside Specification Limits (Nonconforming)	Nonconforming Parts per million (PPM)
$\pm 2\sigma$	69.1462%	30.8538%	308538
$\pm 3\sigma$	93.31928%	6.68072%	66807
$\pm 4\sigma$	99.3790%	0.621%	6210
$\pm 5\sigma$	99.97674%	0.02326%	233
$\pm 6\sigma$	99.999660%	0.000340%	3.4

Figure 1.10 shows the nonconforming parts per million for different sigma quality levels. The amount of improvement for different sigma quality levels can be seen from the graph.

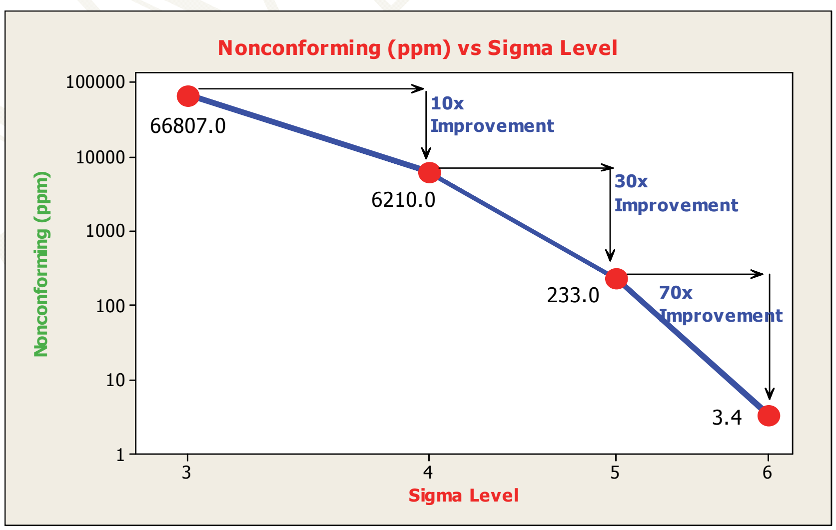

Figure 1.10: Defect Rates in Parts Per Million for Different Sigma Quality Level

Capability Indexes

In the subsequent sections, we will consider *capability indexes* used to determine the process capability. These indexes are Cp, Cpl, Cpu, and Cpk. The capability indexes are based on the assumption that the process measurements follow a normal or approximately a normal distribution.

The index Cp (also called a process capability ratio) is the ratio of allowable spread to the actual spread of the process. The allowable spread is the difference between the upper and lower specification limits (USL - LSL) or the tolerance. The actual spread of the process is 6σ for a normally distributed process. Thus,

$$C_p = \frac{USL - LSL}{6\sigma} \tag{1.1}$$

Usually, the process standard deviation σ is unknown and must be estimated. The above expression is written more appropriately as:

$$C_p = \frac{USL - LSL}{6\hat{\sigma}} \tag{1.2}$$

The process capability ratio, Cp is interpreted in the following way:

Cp < 1.0	Process is not capable of meeting its specification
Cp = 1.0	Process is marginally capable of meeting specifications
Cp > 1.0	Process is capable of meeting the specification limits

The above three cases are shown in Figure 1.11. The interpretation of Cp above is based on the following assumptions:

- the underlying process is stable and in statistical control
- the measurements are normally distributed
- the measurement errors are negligible.

The interpretation of process capability, Cp is different when there is a shift in the process. The calculation of Cp in equation (1.2) assumes that the process has both upper and lower specifications. For one-sided specification limits, the Cp is calculated as Cpl and Cpu (for lower and upper specification limits). Note that all of the above indexes: Cp, Cpl, Cpu, and Cpk use an estimate of process standard deviation and the results obtained by these indexes are very sensitive to the estimated value of standard deviation.

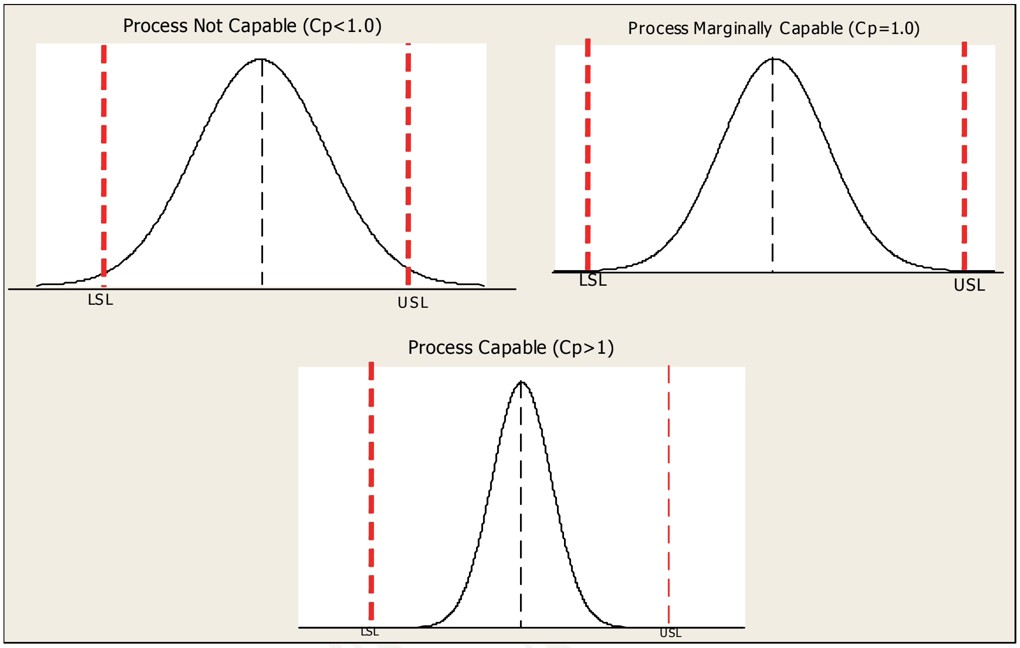

Figure 1.11: Interpretation of Process Capability for Cp<1.0, Cp=1.0, Cp>1.0

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Five Phases of Six Sigma:

- **Define**: identify/define the problem, identify critical customer requirements, define the project, form project teams, and create a project charter.
- **Measure**: outline the process, determine the characteristics critical to quality, identify the metrics, assess the measurement system, collect data, and measure the current process capability.
- **Analyze**: analyze data to determine the root cause (s) of the problem, and the key input and output process variables.
- **Improve**: conduct formal experiments (using Design of Experiments, and other statistical tools), isolate key input process variables from a large number of controllable and uncontrollable factors, and determine the process settings to optimize product or process.
- **Control**: measure the new process capability, document the improved process, and impose control techniques on the critical factors to maintain the gain.

The above is a brief overview of Six Sigma. A complete understanding of each of the above five phases is critical to successful implementation of Six Sigma quality program. Figure 1.15 shows a possible sequence of Six Sigma project execution based on the DMAIC process. The flow chart shows the sequence in which different phases of Six Sigma can be implemented.

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Table 1.7: Lean and Six Sigma Objectives

Lean	Six Sigma
Specify Value What is important in the eyes of the customer?	Define What is important?
Identify the Value Stream What is the entire Value Stream?	Measure How are we doing?
Flow How will the material and information flow through our process?	Analyze What is wrong?
Pull How can we let the customer pull products, rather than pushing product?	Improve What needs to be done?
Perfect How can we optimize our processes?	Control How do we sustain the improvements?

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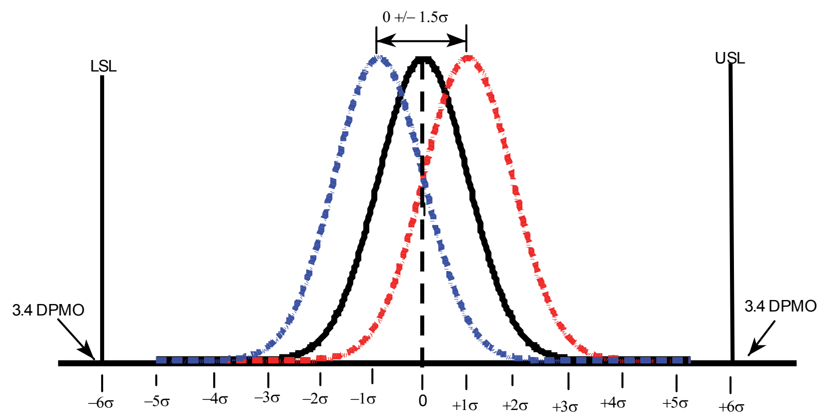


Figure 1.2: A Six Sigma Process

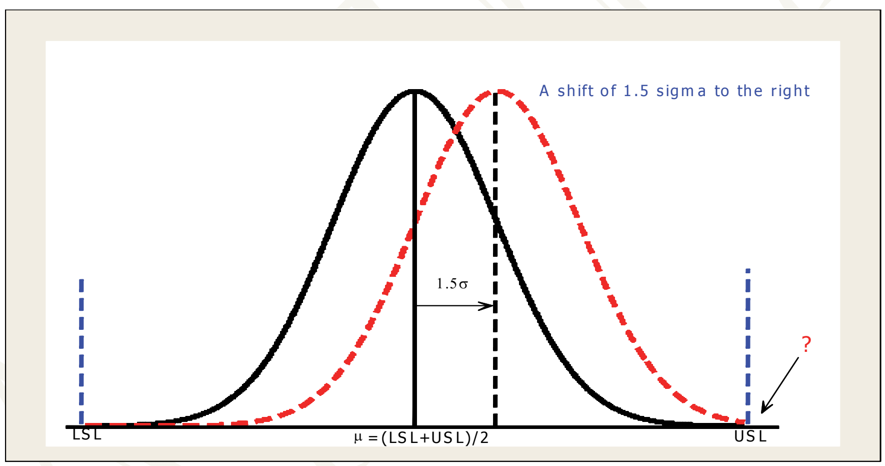


Figure 1.3: A Six Sigma Process with a shift of 1.5 σ to the Right

From Figure 1.3,

$$12\,\sigma = (USL - LSL)$$

or,

$$6\,\sigma = \frac{(USL - LSL)}{2}$$

and, the process center can be given by

$$\mu = \frac{(USL + LSL)}{2}$$

If the process is off-centered by 1.5σ to the right, then

$$\mu = \frac{(USL + LSL)}{2} + 1.5\sigma$$

The percentage outside the upper specification limit can be calculated as

$$P(x > USL) = P\left(z > \frac{(USL - \mu}{\sigma}\right)$$

$$= P\left[z > \frac{USL - \left(\frac{USL + LSL}{2} + 1.5\sigma\right)}{\sigma}\right]$$

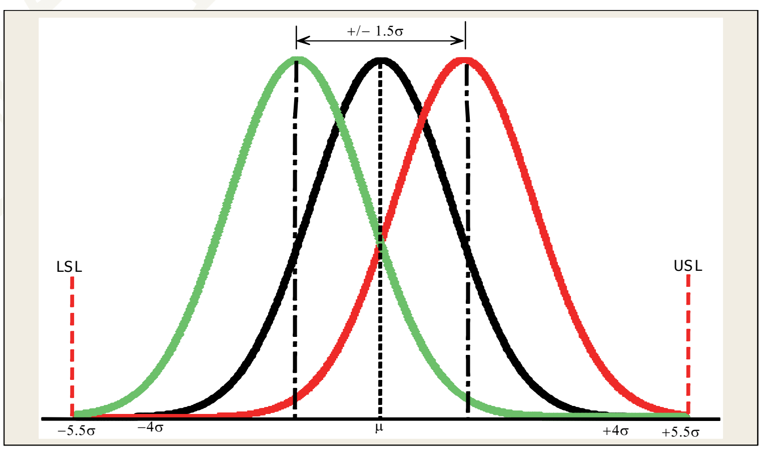
$$= P\left[z > \frac{\frac{USL - LSL}{2} - 1.5\sigma}{\sigma}\right]$$

$$= P\left(z > \frac{6\sigma - 1.5\sigma}{\sigma}\right) = P\left(z > \frac{4.5\sigma}{\sigma}\right)$$

$$= P(z > 4.5) = 0.00000340$$

or 3.4 parts per million (PPM). The percentage falling outside the lower specification limit can be calculated in a similar way when the process mean shifts 1.5σ to the left of the mean.

Figure 1.9: A Four-sigma Process with a Shift of ±1.5σ



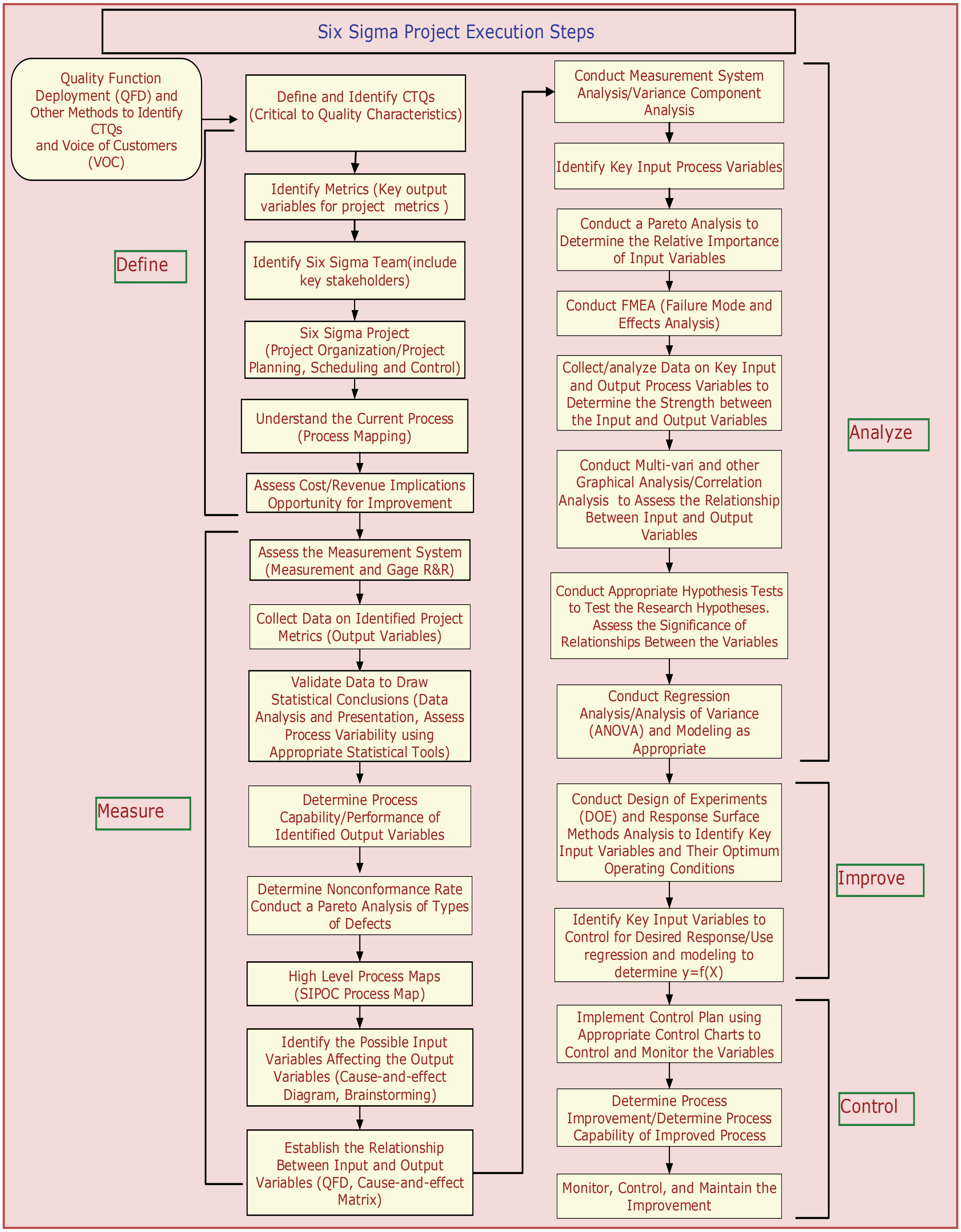
Six Sigma Methodology

The Six Sigma approach is a collection of managerial and statistical concepts and techniques that focus on reducing process variation and preventing product deficiencies. As mentioned earlier, the variability in the process is described by sigma (□). This sigma is the standard deviation of measurements around the process mean. The process that has achieved the six-sigma capability will have much smaller variation. In many processes, we establish a relationship between the response (output) y and input variables x_1, x_2, x_3,......,x_n that is,

$$y = f(x_1, x_2, \ldots\ldots, x_n)$$

The Six Sigma approach identifies the process variables that cause variation in the products. Some of these input variables are controllable and are critical to maintaining quality. These variables must be controlled within a specified range.

*Six Sigma is based on a strategic improvement methodology known as **DMAIC,** which stands for **D**efine, **M**easure, **A**nalyze, **I**mprove, and **C**ontrol. The steps in DMAIC methodology contain several simple to advanced statistical tools — and other process-improvement tools — used to carry out the structured philosophy of Six Sigma. The DMAIC process is briefly explained below followed by a detailed explanation of each.*


Six Sigma Project Execution Steps
Quality Function Deployment (QFD) and Other Methods to Identify CTQs and Voice of Customers (VOC)
Define
Define and Identify CTQs (Critical to Quality Characteristics)
Identify Metrics (Key output variables for project metrics)
Identify Six Sigma Team(include key stakeholders)
Six Sigma Project (Project Organization/Project Planning, Scheduling and Control)
Understand the Current Process (Process Mapping)
Assess Cost/Revenue Implications Opportunity for Improvement
Measure
Assess the Measurement System (Measurement and Gage R&R)
Collect Data on Identified Project Metrics (Output Variables)
Validate Data to Draw Statistical Conclusions (Data Analysis and Presentation, Assess Process Variability using Appropriate Statistical Tools)
Determine Process Capability/Performance of Identified Output Variables
Determine Nonconformance Rate Conduct a Pareto Analysis of Types of Defects
High Level Process Maps (SIPOC Process Map)
Identify the Possible Input Variables Affecting the Output Variables (Cause-and-effect Diagram, Brainstorming)
Establish the Relationship Between Input and Output Variables (QFD, Cause-and-effect Matrix)
Analyze
Conduct Measurement System Analysis/Variance Component Analysis
Identify Key Input Process Variables
Conduct a Pareto Analysis to Determine the Relative Importance of Input Variables
Conduct FMEA (Failure Mode and Effects Analysis)
Collect/analyze Data on Key Input and Output Process Variables to Determine the Strength between the Input and Output Variables
Conduct Multi-vari and other Graphical Analysis/Correlation Analysis to Assess the Relationship Between Input and Output Variables
Conduct Appropriate Hypothesis Tests to Test the Research Hypotheses. Assess the Significance of Relationships Between the Variables
Conduct Regression Analysis/Analysis of Variance (ANOVA) and Modeling as Appropriate
Improve
Conduct Design of Experiments (DOE) and Response Surface Methods Analysis to Identify Key Input Variables and Their Optimum Operating Conditions
Identify Key Input Variables to Control for Desired Response/Use regression and modeling to determine y=f(X)
Control
Implement Control Plan using Appropriate Control Charts to Control and Monitor the Variables
Determine Process Improvement/Determine Process Capability of Improved Process
Monitor, Control, and Maintain the Improvement

Summary

More and more companies are realizing that it is possible to achieve dramatic improvements in cost, quality, and time by using the Lean Six Sigma and Design for Six Sigma (DFSS). Several companies including Toyota, General Electric, Motorola have accomplished impressive results using one or more of the techniques mentioned. However, using only one method — Lean, Six Sigma, or Design for Six Sigma — has limitations. Six Sigma eliminates defects during the production phase, but does not address the importance of quality effort in the research and design phase of a product. Also, Six Sigma does not address the question of how to optimize the process flow, and the Lean principles do not address the use of advanced statistical tools required to reduce variation, defects and achieve the process capabilities needed to be truly 'lean'.

The detailed treatment of Six Sigma, Lean, and Design for Six Sigma can be found in Chapter 1.