PDHonline Course P160 (3 PDH)

An Introduction to Lean Six Sigma - Improving Quality, Efficiency, Profitability, and Customer Satisfaction

Instructor: Timothy D. Blackburn, MBA, PE

2012

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone & Fax: 703-988-0088
www.PDHonline.org
www.PDHcenter.com

An Approved Continuing Education Provider

An Introduction to Lean Six Sigma – Improving Quality, Efficiency, Profitability, and Customer Satisfaction

Timothy D. Blackburn, PE, MBA

Course Content

Course Introduction

Although Six Sigma has been around for years, it continues to grow in popularity and remains effective. Companies are improving quality while becoming more efficient and cost effective, and at the same time delighting their customers. But what is Six Sigma? There are a plethora of thick books on the subjects, and weeks of training that costs thousands of dollars. Would you like a general overview so you can understand the terms, as well as apply some of the effective approaches? Would you like to be able to speak and understand the language of your Six Sigma clients/customers? This course is intended to be an introduction to Lean Six Sigma. It is a beginning of a journey to better understand Six Sigma and its proven methodology. Your Six Sigma customers will be delighted that you speak their language.

What is Six Sigma?

In the 1980's, Motorola pioneered the Six Sigma approach. Today, many major companies use this approach, such as GE, Kodak, Microsoft, Raytheon, IBM, Dupont, Sony, J&J and other pharmaceutical manufacturers. Although often thought of as being applicable primarily in a manufacturing context, it can also be used for services.

Six Sigma is a strategy to improve the quality of products or services by reducing variability, which in turn should result in less waste, all leading to overall business improvement. By improving quality, a side benefit will be efficiency enhancement, as well as identify means to reduce resources while meeting customer requirements (as viewed from the customer's perspective). One reason Six Sigma has been so effective is it focuses on the expectations of the customer.

A goal of Six Sigma is to minimize variation. There are several causes of variation, which generally fall under one of two headings. The first are Common Causes, which include normal, usual, predictable, and typical events. The second are Special Causes, which include abnormal, unusual, unpredictable, and untypical events.

Six Sigma is a systematic method of identifying Critical to Quality[1] parameters, quantifying the process performance, determining causality of variance, improving the variance, and sustaining the performance.

Factors or variables in Six Sigma are often referred to as X's or Y's. The Y's are the essential business aspects or elements, and X's are the factors that will have the greatest impact on the Y's.

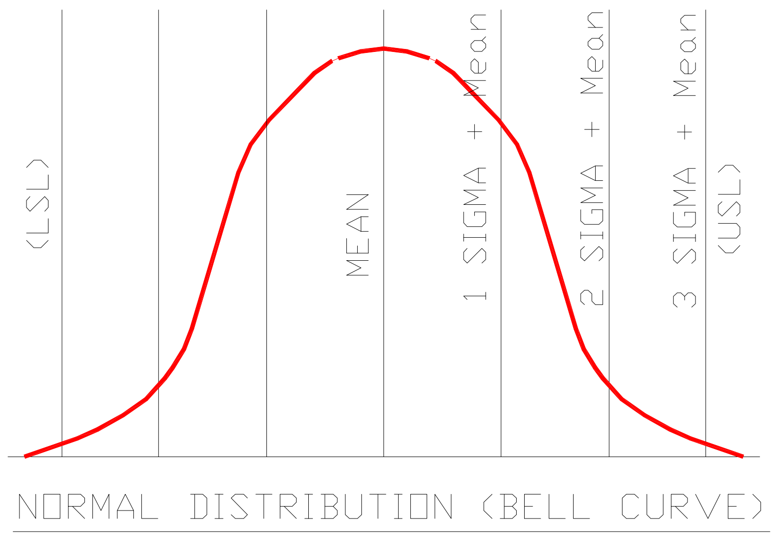
Why Six Sigma?

If we cannot quantify our process, then we are in essence at the mercy of chance. We cannot properly control what we do not understand nor expect predictable performance. Who wants to be left to chance unnecessarily? There is simply more that we can control in our business related to our process than we might imagine (or care to admit). Businesses that do not continuously improve, exceed customer expectations, maintain high quality, become more efficient, etc. may become extinct. Six Sigma is also a means to stay alive and thrive as a business in an increasingly competitive environment. As engineers, we need to understand Six Sigma, whether we are employed by or consult with a company who uses the Six Sigma approach. These are proven quantitative and methodical approaches that have been proven successful.

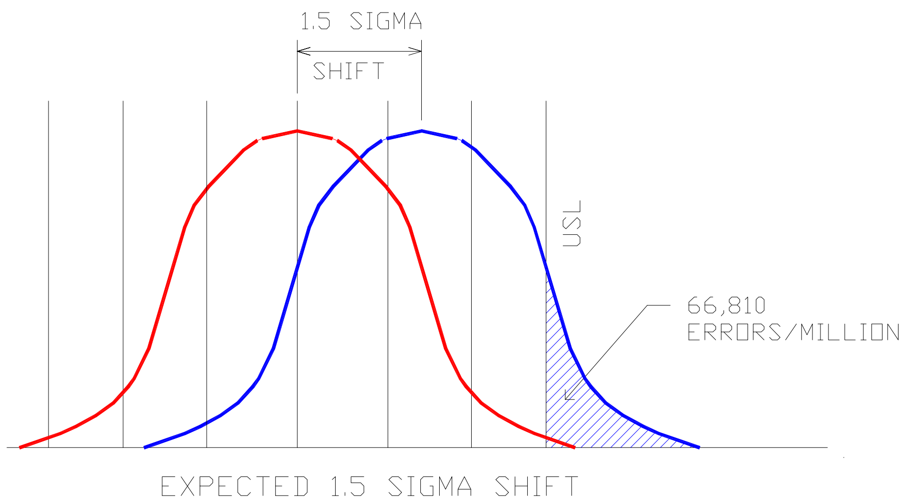
The Statistics behind Six Sigma

You may be well versed in statistics, need a review, or an introduction. The following are some essentials of Statistics that are essential to understanding elements of the Six Sigma approach. However, we will not perform extensive detailed calculations beyond the basics, nor attempt to teach beyond the concepts – these are outside the scope of this course. First, let's review the familiar bell curve. The following is a diagram of normally distributed data:

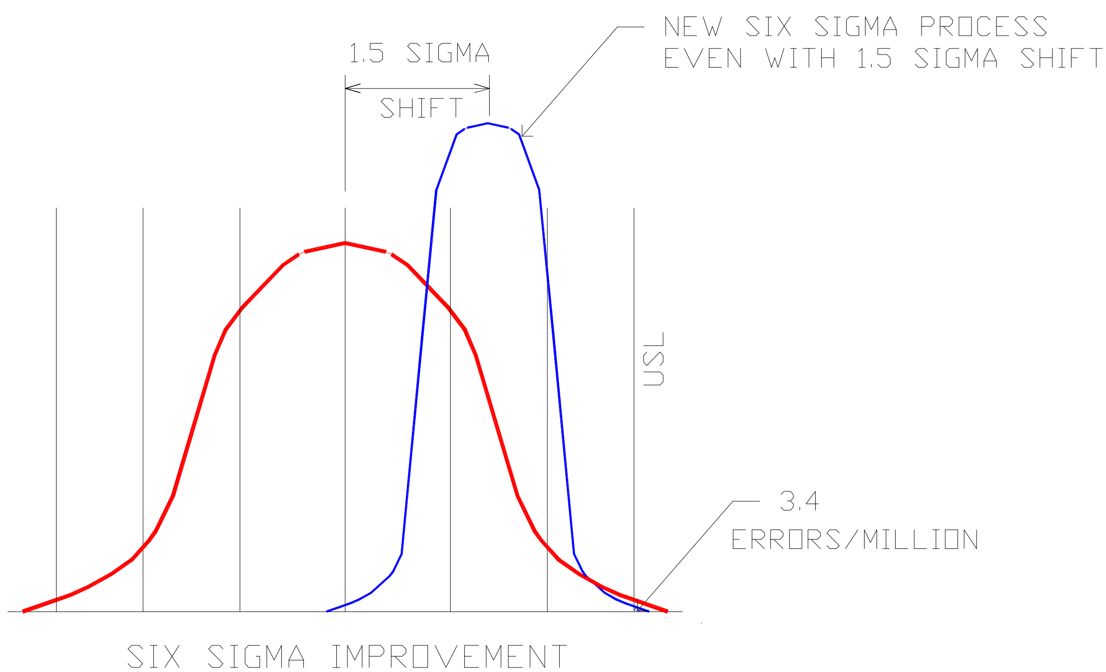
[1] CTQ's (Critical to Quality) are the primary quantifiable aspects of a product/process and associated performance standards or specification limits which the customer expects to be met.



Often, when data is plotted, the result is the familiar bell curve as shown above. For a process, there should be a Lower Specification Limit (LSL), and an Upper Specification Limit (USL), naturally occurring at three standard deviations (Sigmas or σ) from the Mean. The amount outside the Limits reflect the errors in a processs. Over time, experience has shown that the mean will shift – Motorola determined that a reasonable shift is 1.5 sigmas. When a 3 sigma operation shifts 1.5 standard deviations towards the USL, for example, there is a potential of having 66,810 errors out of a million. This is illustrated on the following graphic:



However, if the process is improved such that six sigma will fit inside the USL and LSL, there will only be 3.4 defects or errors per million even with the expected 1.5 sigma shift over time. See the diagram below:



A Six Sigma quality goal (arguably nearly impossible to achieve in the real world, but a noble goal nonetheless) would result in 99.99966% of our outputs being within acceptable limits, or 3.4 errors in one million, or plus or minus Six Sigmas beyond the Mean. When data follows a normally distributed bell curve, we find the following errors or defects outside the noted quantity of standard deviations from the Mean when assuming a 1.5 sigma shift:

Standard Deviations from Mean	**Errors or Defects per Million**
One Sigma	690,000
Two Sigma	308,000
Three Sigma	66,810
Four Sigma	6,210
Five Sigma	320
Six Sigma	3.4

What do we mean by "mean," and "standard deviation"? First, there are two primary fields of statistics – Descriptive and Inferential. Descriptive Statistics provides the characteristics of a group of observations. In this field, we have the above criteria such as Mean, Mode, Standard Deviation, etc. The second field is Inferential Statistics, which make conclusions about data based on analysis, and can include hypothesis testing.

A focus of Descriptive Statistics is to evaluate measures of central tendency. These include Mean, Mode, and Median. Mean is the average of all the data observed or the summation of the data divided by the total observation count (n). Mean is described by the following variables:

- Population – μ
- Sample – $\overline{X}$

Median is the middle value – arrange in lowest to highest value in descending order, and choose the central value. Mode is the value that is observed the most frequently.

Another focus of Descriptive Statistics is to evaluate measures of spread. These include range, variance, and standard deviation (sigma). When plotting a bell curve, there will be a lowest value and highest – the distance between these is the Range. Variance reflects the degree to which the values are off the mean. (Variance is something Six Sigma wishes to minimize.) Variance is calculated by summing the square of each value minus the mean, the total of which is divided by the total data count minus one. Standard deviation is simply the square root of

Variance, and indicates the expected variation within a normally distributed set of data. The following is a formula to estimate Standard Deviation:

$$\text{Standard deviation} = \sigma = \sqrt{\frac{\sum (X_i - \overline{X})^2}{n-1}}$$

Where X_i = each data point, $\overline{X}$ = the mean, and n = total count of data being observed.

Spreadsheets and other software can calculate descriptive statistical summaries, or you can calculate them yourself. The following is an example:

	Data	$(X - \overline{X})^2$		
	5	0.89		
	5	0.89		
	5	0.89		
	7	1.12		
	5	0.89		
	6	0.00		
	3	8.65		
	3	8.65		
	3	8.65		
	7	1.12		
	5	0.89		
	6	0.00		
	9	9.36		
	8	4.24		
	9	9.36		
	8	4.24		
	7	1.12		
Totals	101	60.94		
n	17			
Mean ($\overline{X}$) =	**5.94**			
Variance	=	60.94 / (17 - 1)=	**3.81**	
Standard Deviation	=	**1.95**	(Squareroot of Variance)	

Is any of this starting to make sense? Again, a Three Sigma approach to Quality would result in about 66,810 errors or defects per million, but with Six Sigma the goal is to nearly eliminate errors and defects. Now that you have reviewed the fundamentals of Descriptive

Statistics, go back and review the beginning of this section if necessary to better apply to Six Sigma.

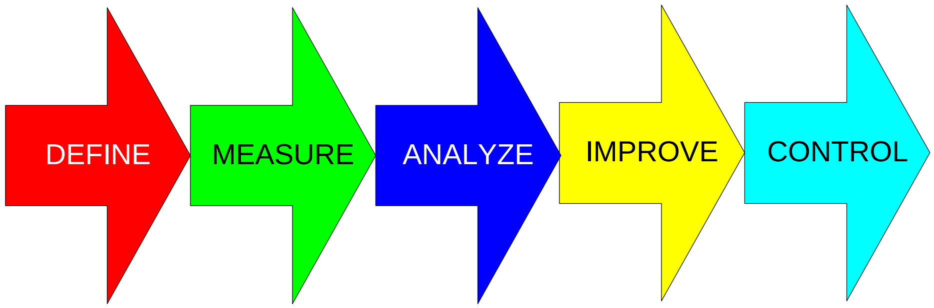
There are many other essential aspects to the field of statistics as related to Six Sigma. The following is a brief summary of common statistical terms used within Six Sigma, although the details of how to calculate are beyond the course scope.

- *Hypothesis testing* uses a variety of statistical tools to analyze data until it eventually fails to reject the null hypothesis and accepts the Alternate Hypothesis. A Null Hypothesis (H_0) assumes there are no differences between parameters for multiple populations, that is, observed differences are a result of random chance. An Alternate Hypothesis (H_a) states that differences or relationships between two populations are not the result of chance or a sampling error, and are therefore true. In Six Sigma, Hypothesis testing is used to determine if data variations in separate groups are due to common cause or natural process variation. *Chi Square* testing is a popular discrete data hypothesis testing method, which can perform analysis for Goodness of Fit, Test for Homogeneity, and Test of Independence.
- *Confidence Intervals* indicate the percent of certainty that a true value lies within a range. This is usually calculated by software.
- *Correlation* is a calculation that indicates the certainty that two values are related. Be careful, however – high correlation between two values is not necessarily an indication as to cause and effect. Something else could be affecting both variables in a relational manner.
- *Regression Analysis* can be used to predict future performance using measured data. The relationship between variables is expressed by fitting a line or plane such that the data points are evenly distributed. A common form of this is Linear Regression, where a best-fit statistical line is plotted on a scatter diagram.

There are many other statistical elements to Six Sigma, but are beyond the scope of this introductory course, both in explanation and practice. Complete courses are dedicated to methods.

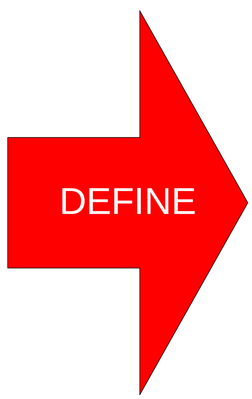
Next, let's review the fundamental approach and methodology for implementing Six Sigma.

Six Sigma Fundamental Approach - the DMAIC Methodology



THE DMAIC MODEL

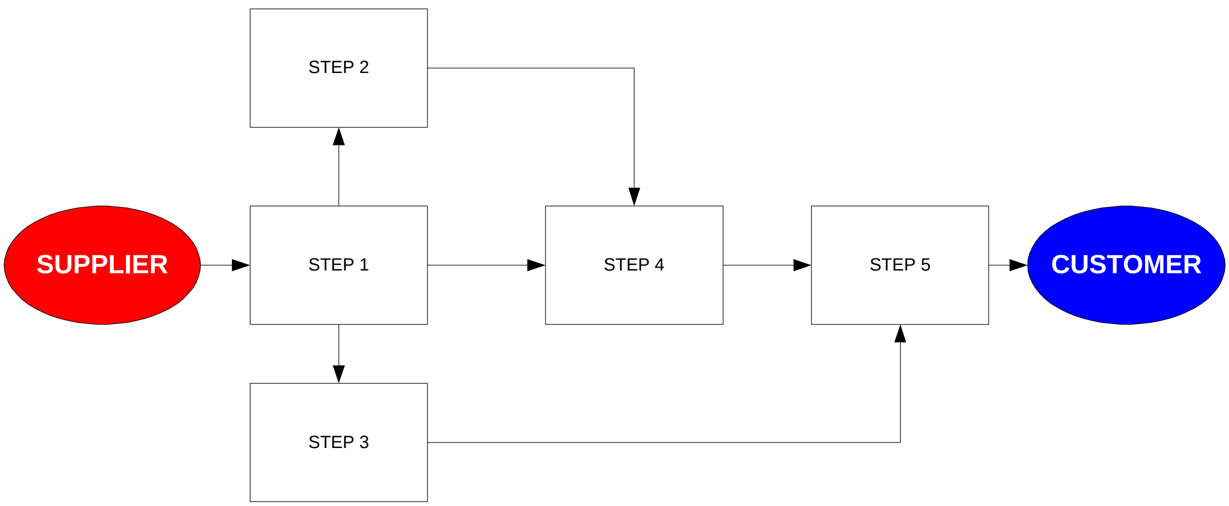
The primary approach to implement Six Sigma methodologies are contained within the acronym DMAIC (pronounced "duh - may - ick") where D = Define, M = Measure, A = Analyze, I = Improve, and C = Control. The following are the categories with further descriptions. (The bulleted items are not necessarily in order.)



1. Define

- During the first step, the purpose and extent of the project is defined. The business case is determined. The team should agree on the goals and scope of the Six Sigma project, as well as financial/performance expectations.
- Background is included, as well as clearly stated objectives or improvements needed.

- Customer needs are identified. The VOC (Voice of the Customer)[2] elements are translated to CTQ's (Critical to Quality) elements. A Kano analysis is a technique to determine what customers really want (Critical to Quality), and those that add no value (non-value-added). There are Dissatisfiers (expected features that if not there will disappoint the customer), Satisfiers (allow one to remain in the market), and Delighters.
- The team charter is developed, and agreed to.
- Begin to map the process. A rudimentary, high-level map of the process is developed during this stage. The following is the concept of a process map:



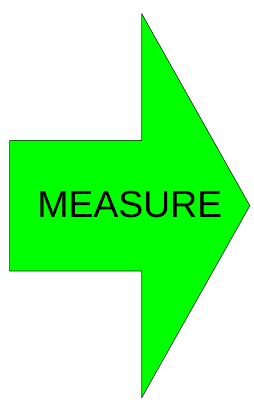
PROCESS MAP

- Another tool that is used is a SIPOC map, which allows identification of (and is an acronym for) Supplier, Input, Process, Output, and Customer. Identify KPOV (Key Process Output Variables) which include quality, cost, and time. The following is a graphic that can be used to develop the SIPOC map.

[2] VOC are expressed customer requirements and expectations

SIPOC				
SUPPLIER	**INPUT**	**PROCESS**	**OUTPUT**	**CUSTOMER**
____________	____________		____________	____________
____________	____________		____________	____________
____________	____________		____________	____________
____________	____________		____________	____________
____________	____________		____________	____________
____________	____________		____________	____________
____________	____________		____________	____________
____________	____________		____________	____________
____________	____________		____________	____________

- Develop project management plans and documentation, such as schedules, list stakeholders, identify means to manage risk, communication protocols, etc.



2. Measure

- Step 2 involves measuring aspects of the process in its current state.
- Further refine or develop a Value Stream Map (VSM). On this map, all the steps required to produce a product or service should be identified. The objective is to discontinue any step that does not add value, as well as reduce the associated resources.

Begin at the start of the process until it's completion. The map is similar to the process map described earlier, but with data added.

- Create a plan to gather data that can be used to indicate the problem, as well as establish a baseline.
- Verify the data gathering approach using Measurement System Analysis (to ensure consistent and reliable data). There are various methods for this, the specifics of which are beyond the scope of this course, but include Gage R&R, Bias Analysis, Stability Analysis, Discrimination Analysis, or Kappa Analysis, defined as follows:
  - Gage R&R measures the reliability and repeatability that result from measurement devices and people
  - Bias Analysis measures the distance between the correct answer and the averaged observation
  - Stability (or Drift) Analysis confirms the measurements don't shift over time
  - Discrimination Analysis confirms the ability to detect changes in the characteristic
  - Kappa Analysis is used to confirm non-quantifiable attributes, which the previous methods are unable to evaluate
- Gather the data and establish baselines, and evaluate data for patterns
- Perform Process Capability Analysis, which compares the actual process variation against the desired results. Under a state of statistical control, Process Capability measures indicate the normal behavior of a process. Process capability indices are commonly C_p (related to the allowable process spread to the actual), and $C_{pk.}$ (ratio of actual spread to specification, for an off-center process) as follows: (Also see later discussion of Process Control Charts)

  - $C_p = \dfrac{UCL - LCL}{6\sigma}$

  - C_{pk}
    - (Upper) $C_{pu} = \dfrac{UCL - \mu}{3\sigma}$

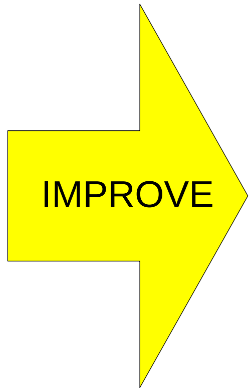
    - (Lower) $C_{pl} = \dfrac{\mu - LCL}{3\sigma}$

- Revise the purpose and extent of the project if needed.
- Utilize the data to assist in determining process capability

3. Analyze

- Step 3 involves analyzing the data collected in Step 2, which will enable deeper causality evaluation
- Using the data, continue to evaluate steps that add value to the process (Value-Added), and those that do not (Non-Value-Added). Anything that reduces quality, results from unnecessary actions, over work, or aspects for which customers are not willing to pay, etc. are non-value added steps.
- Analyze the process: Calculate Process Cycle Efficiency (PCE)[3], and compare against best in class goals. (Although PCE will vary between industries, a PCE exceeding 25% is generally considered world-class.) Look where other problems may exist as related to the process flow.
- Perform Root Cause Analysis: Documentation can include cause-and-effect diagrams and FMEA (covered later), and tools to enable the team to narrow causes using Pareto charts, multivoting (allowing team members more than one vote on line items and summing), and stratification (an approach to aid in determining essential patterns in data by breaking down a number into meaningful categories). Statistical methods are also employed, such as ANOVA and Regression Analysis.

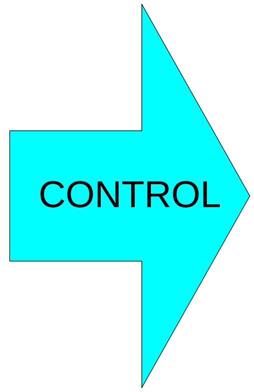
- Develop hypothesis and test and run pilots (if not deferred to the next step).



4. Improve

- After analyzing, it is time to turn the theoretical to the practical – develop and implement pilot improvements, followed by full-scale application improvements.
- Solutions should be linked to root causes with high degrees of certainty at this phase
- For a Lean project, also include the chosen method
- Revise the VSM as to what it should be
- Create plans to implement
- Implement the improvements

[3] Process Cycle Efficiency equals Value-added Time divided by Total Lead Time. Total Lead Time equals Quantity of Items In-Process divided by Average Completion Rate.

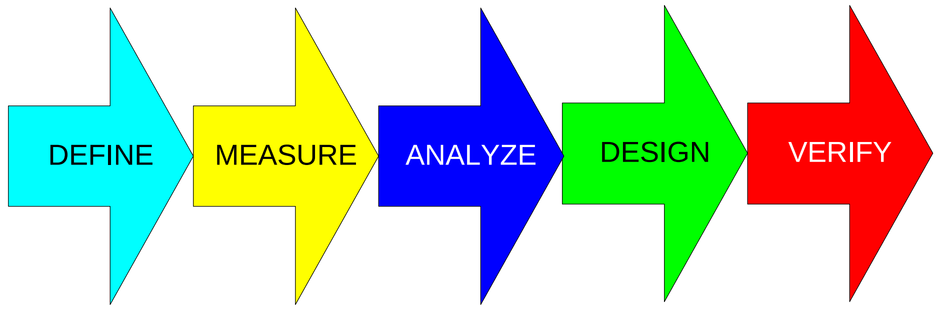


5. ***Control***

- By now, the issues should be resolved and improved. *But don't stop yet . .*
- Quantitatively, confirm the solutions are effective before hand-off. If not, go back to earlier steps and begin again.
- Confirm the changes comply with policies (internal and external)
- Standardize the process to maintain the correction, and develop process control plans
- Consider additional improvements needed
- Hand off the project to the user
- Summarize lessons learned/post mortem
- Celebrate!

Design for Six Sigma – DFSS and DMADV

Although the above (DMAIC) applies primarily to existing operations, Six Sigma approaches can be incorporated into new projects as well. Design for Six Sigma (DFSS) should facilitate breakthrough performance in new product and process development. In Six Sigma, DFFS is provided via the DMADV model. DMADV is similar to the more traditional DMAIC, but focuses on including quality, cost savings, and faster time-to-market aspects *into* the design.



THE DMADV MODEL

DMADV is an acronym for the following five phases: define, measure, analyze, design, and verify. These steps are to ensure the new system or process will meet the expected needs of the customer. Briefly, the following are the elements of DMADV:

1. *Define:* Essentially the same as DMAIC.
2. *Measure*: The initial focus will be on the customer. This will require measuring and determining customer needs, as well as specifications. In this step, it is essential that we understand the customer's needs, as well as the market.
3. *Analyze:* Again, the focus is on the customer, where process options are analyzed in an effort to meet the customer needs.
4. *Design:* Here the term changes from DMAIC. The Customer's needs must be met through the design, by applying robust design methodologies. We are expected to provide innovative solutions through design.
5. *Verify*: Confirm that the design is capable of the performance needed to meet the customer's needs.

Key Participants

Although elements of Six Sigma should and can be used by anyone, Six Sigma as a discipline contains specific requirements and specializations. Individuals should be properly trained and certified to oversee and carry out Six Sigma efforts, taught by people appropriately trained and experienced (Sensei). These are often classified by Belts, depending on the degree of training and experience. But management buy-in, commitment and support are needed as well. Goals should be established, as well as measures enacted to achieve goals (Hoshin Kanri).

Project Champions or Sponsors

A Champion or Sponsor can be a member of the leadership team who is assigned the responsibility of selecting Six Sigma projects, and is accountable for a project's results. Only if management takes Six Sigma seriously will it likely be sustained. Project champions or Sponsors promote the Six Sigma initiative, and commit resources. They should remove hurdles to success.

Six Sigma Consultants

Consultants may be required to provide experience and expertise in Six Sigma business improvement implementations. These can be hired for a limited time to advise and facilitate Six Sigma implementation, as well as assist with training.

Green Belt

Green Belts are the key individuals responsible for facilitating specific projects. These individuals should present demonstrated leadership, technical (some statistics), project management, organization, and other skills in addition to formal Green Belt training and certification. Typically, Green Belts are dedicated 50% of their time to initiatives.

Black Belts

Black Belts are at an advanced stage above Green Belts, and are expected to have further presentation, financial, and business acumen. They are expected to be well versed in statistics. Black Belts are expected to manage multiple projects, as well as focus on business aspects. They advise and mentor Green Belts. Black Belts are typically committed full-time to initiatives.

Master Black Belts

Master Black Belts are at an advanced stage above Black Belts. They are expected to have completed several successful projects, as well as have mentoring experience. They certify Black and Green Belts. Their knowledge of statistics is expected to be accomplished, and they are to have additional training. They also are to possess even greater business acumen, focus, and oversight.

Six Sigma Teams

Assign qualified and experienced individuals to Six Sigma teams. The Six Sigma teams should be committed to their assignment. These assignments generally fall within one of two methods. The first is the Project approach, which may commit team members' full time for the duration of the project (although the Black Belt should be full-time). The second is Kaizen, which is generally understood to be an intense and rapid attention to a project (typically a week or less). Kaizen is literally a Japanese word that means gradual unending improvement (we would think of this as continuous improvement), but often refers to a "blitz" effort by a dedicated team in a short time frame. It is as if the team members are on vacation from their primary assignments to intensely focus on an initiative. In some cases, a radical, revolutionary improvement is needed, which is a Breakthrough Kaizen (also called Kaikaku). In both cases, the teams should follow DMAIC.

An Efficient Team Activity - Brainstorming

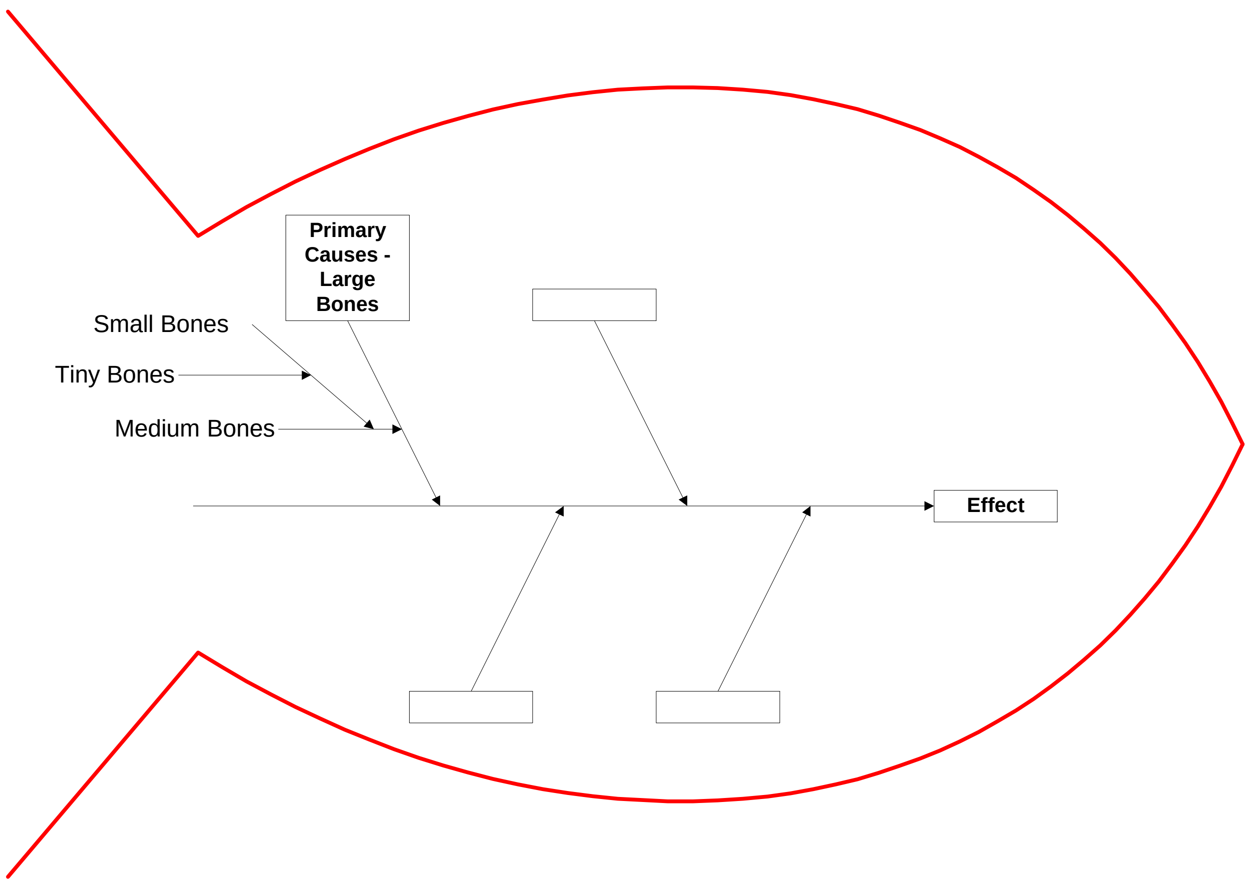
Brainstorming is used to generate as many ideas as possible from a group. Extremely creative ideas can come out of this approach, some of which do not result in value, but others helpful. However, it is important to have a structure/rules for brainstorming. Set up the session so everyone can be heard in an orderly manner without value judgments or discussion initially (for brainstorming to be effective, avoid arguing whether ideas are valid initially.) Record ideas exactly as they are stated without paraphrasing if possible. Using five "W's" and one "H" is a good approach – ask why, what, where, when, who, and how. Techniques to organize and document brainstorming results include Cause and Effect Diagrams (below) and Affinity Diagrams to organize data (self-stick notes under various categories).

Six Sigma Tools, and Diagrams

There are numerous materials available on Six Sigma that provide tools, and diagrams with applications to virtually every scenario. The following is meant to be an overview and introduction, and is not all-inclusive or fully descriptive. However, the following represent some of the most common and referenced tools and diagrams used in Six Sigma:

Cause and Effect Diagram

Often, there are so many modes of potential sources of causality that the full picture is difficult to absorb. The Cause and Effect Diagram, (also called Fish-bone or Ishikawa Diagram), is helpful in graphically categorizing ideas quickly in a logical manner. The output is the effect (a statement of the problem), and the "bones" are the causes. Assign primary potential causes (or large bones), and begin to list sub causes under each (medium, small, and tiny bones). Usually, most causes fall under one of five categories: Man, Machine, Material, Method, and Environmental. Brainstorming above can then be used to populate the diagram further (major causes).



Matrix Diagrams

Matrix diagrams can be used in the decision-making process to choose between alternatives. Scoring/weighting can be used. The team can in essence "vote" on the ratings to populate the table.

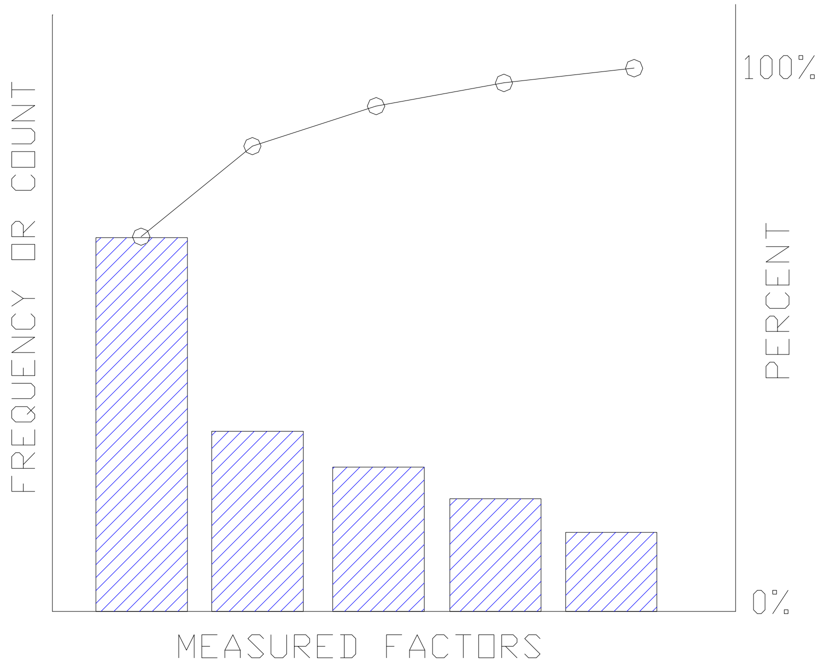
Scatter Diagrams

Scatter Diagrams show possible relationships between variables. With this, one can test for cause and effect relationships, and variable interrelationships (correlations). Software is available to "best fit" line graphs (see Regression Analysis).

Pareto Diagram

According to the Pareto principle, the greatest numbers of defects or errors can be caused by a small number of factors. This principle was named after the Italian economist Vilfredo Pareto, who concluded that about 20% of people control approximately 80% of society's wealth. The Pareto effect as related to quality holds that 80% of the problems usually result from 20% of the causes. By focusing on the few problems that are significant, therefore, we can realize significant impact on overall quality. A Pareto diagram is a tool to accomplish this improvement.

A Pareto diagram stratifies characteristics of data, which can aid in identifying causal factors. To populate a Pareto diagram, determine data to be collected, and sort in categories with highest frequency to lower. Pareto charts include a variety of information, such as type, number, cumulative number, percentage, and cumulative percentage. Then graph the data on a bar graph, with the highest incidences to the left. The "y" axis (to the left) will reflect frequency or count, i.e., contributions to defects, errors, delays, etc. The "x" axis contain factors that are being measured. Add a second axis to the right (parallel to the frequency axis) that indicates cumulative percentage. Then, plot a line of the accumulative effect. The chart can be used to identify the few factors that cause most problems, which correlate to items that have the highest cumulative effect on the diagram. A process with a clear Pareto effect will have one or more of the bars significantly higher than the others. However, a process with no Pareto effect will not have significantly unequal height bars. A Pareto Diagram can be drawn later after the improvement to confirm performance. The following is an example of a Pareto diagram.



PARETO DIAGRAM

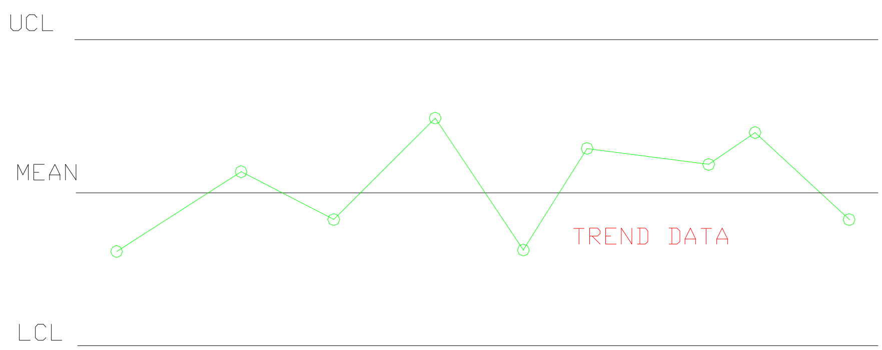
Histogram

A Histogram (or Frequency Distribution Chart) is a bar chart, and is used to indicate measurement variations of the same items. The chart can then be used to illustrated variability, as well as distribution (positively or negatively skewed about the Mean.)

Control Charts

Statistical Process Control (SPC) utilizes Control charts to organize processes into logical and manageable sizes, and visually illustrate the processes. These charts are helpful in understanding the degree of statistical process control, as well as for trending. Control charts are generally categorized in one of two types. The first is "Variable" where data is plotted in quantitative units. The second is "Attribute" where value statements are included. There are a variety of chart types within both categories.

Control Charts are plotted against three parallel lines - the mean is the centerline, the top line is UCL (Upper Control Limit) which may be two to three standard deviations above the centerline, and the lower is LCL (Lower Control Limit), also two to three standard deviations below the centerline. After the data is plotted, variations become evident. As noted previously, a goal of Six Sigma is to minimize variation. The following is an example of a Control chart:



CONTROL CHART

Other Graphs and Charts

A wide array of graphs and charts (such as might be generated from a spreadsheet) are also useful. Charts can include line graphs (which show the relationship between sets of data), plus Bar Graphs, and Pie Charts.

Other Six Sigma Tools and Techniques

As with charts and approaches referenced in the previous section, the following are intended to be an overview and introduction, and are not all-inclusive or fully descriptive. However, the following represent common and referenced tools and techniques used in Six Sigma.

ANOVA (ANalysis Of VAriance)

Using ANOVA, we can determine if the mean of a sample is statistically different from two or more others. This can help us determine the degree of higher impact from variables, or to select best options. ANOVA divides data in such a way to enable a hypothesis test to estimate variance components. Three models of ANOVA include fixed, random and mixed.

Design of Experiments (DOE)

A statistical technique, DOE includes various aspects used in planning, design, data acquisition, as well as analyzing and interpreting the data. DOE determines X and Y factor relationships through a structured and organized method. DOE is also helpful to best utilize resources.

Quality Function Deployment (QFD)

QFD enables the design process to be developed with a customer focus. It includes a methodology with procedures to focus on customer requirements, including prioritization. After identifying and quantifying customer requirements, key critical parameters can be developed. In Six Sigma, QFD helps to prioritize actions to improve processes or products to meet customers' expectations. In summary, Six Sigma teams can better focus on what is really important to the customer by utilizing this approach.

T-Test

When there are small sample sizes, the results can be validated using the T-Test. This is used with small sample sizes, less than 30, and when the population standard deviation is not known. By determining the statistical difference between groups, it can be determined if the differences are not a result of chance.

FMEA (Failure Modes and Effects Analysis)

FMEA is a structured approach to evaluating possible modes of failure, the effects of the failures, and a weighting for each mode based on severity, occurrence, and detection. This information is contained in a table or spreadsheet. The higher the weightings the greater the attention needed (i.e. higher weightings should be higher priorities). Weightings are generally 1-10. The three weightings are multiplied to yield the Risk Priority Number (RPN) for each mode. Note that RPN’s can range from 1 to 1,000 (i.e. 1x1x1 up to 10x10x10). Generally, address higher RPN line items initially, and all RPN’s over six.

When considering causes of failure, consider the six M’s: Materials, Method, Machines, Manpower, Measurement, and Mother Nature. In addition, the FMEA approach (performed in a table) should also recommend actions and assigned responsibility, and confirm resolution. The following is a typical table that can be used in a FMEA analysis.

FAILURE MODES AND EFFECTS ANALYSIS (FMEA) TABLE															
Product or Process:								**Performed by:**			**Date:**				
Existing Operation Evaluation									***Improvement Initiatives***						
Process Step	**Potential Mode of Failure**	**Potential Effect of Failure**	**Severity Value**	**Possible Causes**	**Occurrence Value**	**Controls**	**Detection Value**	**RPN = (S*O*D)**	**Recommended Actions**	**Responsible**	**Actions Taken**	**New Severity Value**	**New Occurrence Value**	**New Detection Value**	**New RPN = (S*O*D)**

Other Six Sigma Related Practices

The following represent other affiliated aspects of Lean Six Sigma initiatives. These work together to accomplish business goals.

Lean Manufacturing

Lean Manufacturing concepts are integral to Six Sigma initiatives. When combined, Lean Six Sigma integrates Lean production approaches with Six Sigma methodology. While Six Sigma focuses on the process, Lean focuses on the product. Six Sigma initiatives result in minimizing rework and scrap, while Lean reduces inventory levels and cycle time. Both are customer focused, with Six Sigma focusing on expected performance, while Lean responds to customer demand. Lean looks at the overall elements of the process, while Six Sigma has more of an individualized process view.

Lean concepts include eliminating waste (Muda), maintaining low inventories, reducing cycle times (time it takes to perform a function or produce a product), and eliminating non-value added aspects. Non-value added aspects are eliminated from the process. Most importantly, Lean concepts follow a "pull" strategy, that is, the focus is on the customers' demands and when they need certain deliverables – take no steps until a down-stream customer requests. (Examples of Pull are Just-in-time and Kanban[4]). All the activities should result in a high-quality product that is responsive to the customers' demand, while the process remains efficient and economical. The goal is perfection, perhaps never attainable in a perfect sense, but a goal to be worked towards in a Continuous Improvement philosophy. In simpler terms, Lean concepts expect to do more with less while delivering the customers' expectations.

"Takt Time" is a measure of Lean, and is calculated by the available weekly work time divided by customer demand per week. For example, assume an operation requires 6300 minutes per week to produce 6500 units. Takt Time = 6300/6500 = 0.97, or a unit must be produced every 0.97 minutes to meet customer demand. This can be compared against cycle time (the actual production rate) – when lower than Takt Time, you will have excess inventory. All the processes should run at the same rate to avoid inventory accumulation. "Heijunka" is a level

[4] Kanban is the Japanese word for "card," and can refer to an actual card with information related to components needed at a particular step in the process. These are used as visual signals, which control or trigger components needed at various steps of the production process. Kanban can also include cross training of staff to perform different functions.

schedule that minimizes order variations. A goal is to approach maximum worker efficiency when we match work content with Takt Time (Heijunka).

To summarize, Lean Six Sigma seeks to minimize waste, which can come from producing excessively, defects, unnecessary inventory, not processing appropriately, excess transportation, waiting, and motion that is not needed. The DMAIC process discussed previously should be able to also identify aspects to make our operation more lean and therefore more cost and time efficient.

5S

The concept behind 5S is to maintain a safe, clean, organized, and a high-performance work environment. The 5S's are:

- Sort – Eliminate anything that isn't needed
- Set in order – Organize or Simplify. Keep items in a location where they are easily retrieved and replenished.
- Shine – Keep clean
- Standardize – Develop standards for the first three S's
- Sustain – Follow the procedures

Although this seems to be common sense, many work environments are unorganized, leading to safety concerns, product mix-ups, difficulty finding items (resulting in longer cycle times), etc.

TPM (Total Productive Maintenance)

Equipment and system failures add cost to an operation. Why wait until something fails? TPM includes Preventive and Predictive Maintenance. *Preventive Maintenance* includes intelligently performing necessary maintenance at appropriate intervals before failure occurs. A CMMS (Computerized Maintenance Management System) is helpful in keeping track of workorders, including recording and automatically issuing workorders at the appropriate time. *Predictive Maintenance* is performed based on gathered data (such as vibration analysis, etc.).

OEE (Operational Equipment Effectiveness)

OEE focuses on improving the performance of equipment and machinery, as well as avoiding making the wrong purchases. OEE focuses on the greatest areas of improvement that will have the greatest return. The OEE can be expressed by A*B*C, where A = Availability, B = Performance Rate, and C = Quality Rate. OEE can be used to illustrate how improvements will result in better changeovers, reliability, quality, etc. OEE can be calculated based on production rates or schedule. $OEE_{production}$ equals actual output (of acceptable quality) divided by theoretical scheduled output. $OEE_{schedule}$ equals actual process time divided by theoretical process time.

Poka-yoke

Poka-yoke defines an approach to prevent mistakes. *Mistake proofing* are means built into a process to prevent errors from proceeding from one stage of the process to another (such as automatic rejects, etc.) *Mistake prevention* are means to prevent the process from making a mistake. Poka-yoke is used where there are human interactions/interventions, for repetitive tasks requiring physical manipulations, where errors have previously occurred, and where there are likelihood of predictable errors.

Keys to Six Sigma Program Success

Six Sigma can be successful. It has been proven repeatedly at many companies, including Fortune 100. But it is about people and the approach – both are essential to success.

- *People*: People involved in the process should focus on how customers' view value. They need to be results oriented, and be able to assign and predict resource needs. They need to ensure decisions are based on data. They need to be able to manage performance through setting goals, as well as track the process and results. They need to be tenacious, and not accept second best – go for the breakthrough goals. They need to approach their tasks with passion, yet remain able to actively listen and effectively communicate. They need to be assertive without alienating, working through a team to achieve excellence. "All of us are smarter than one of us," someone once said, which remains true for Six Sigma.

- *The Approach*: As noted earlier, it is essential that management support and allocate resources if Six Sigma is to be effective. The goals of Six Sigma initiatives must clearly link and support business objectives and goals. As well, initiatives should have a positive impact to business profitability, with the linkage clearly expressed. Resources should be dedicated and trained for their roles. And, while tools and approaches are important, they should not be rigid to the point that the Six Sigma process is stifled – Six Sigma is a framework where the spirit of the law is as important as the letter.

Course Summary

In this course, we have learned the fundamentals/definitions of various aspects of Six Sigma and related approaches to improving our processes. The next step is to implement portions or the complete approach to your application. But this will take commitment, as well as additional training. So go forth and be safe, efficient, produce quality products and services, make a good profit, and delight your customers! And, enjoy the ride . . .

References:

Websites:

- www.ASQ.org
- www.isixsigma.com
- www.motorola.com

Books:

- "Design for Six Sigma: Innovation for Enhanced Competitiveness;" Gregory Watson
- "The Lean Six Sigma Pocket Toolbook;" George, Rowlands, Price, and Maxey; Published by McGraw-Hill, 2005
- "Lean Thinking," Womack & Jones, (New York, Simon & Schuster 2003)
- "The Six Sigma Black Belt Handbook;" McCarty, Daniels, Bremer, Gupta, 2004