## SIX SIGMA

The core of Six Sigma engineering was developed at Motorola, GE, and a few other companies. Six Sigma became a movement when Jack Welch, GE's legendary CEO, announced an initiative to bring all divisions of the company to the Six Sigma level of quality. At that point, Six Sigma moved from an engineering approach to a quality management system in its own right, and also, unfortunately, became a confusing buzzword as well.

The confusion is created by the fact that Six Sigma can be defined as a goal (measured in number of defects per million opportunities), or as a management or executive initiative that includes commitments to Six Sigma or other breakthrough goals, or as a set of processes to achieve those goals.

### Three sigma rule

In statistics, the **68-95-99.7 rule,** or **three-sigma rule,** or **empirical rule,** states that for a normal distribution, almost all values lie within 3 standard deviations of the mean.

About 68% of the values lie within 1 standard deviation of the mean (or between the mean minus 1 times the standard deviation, and the mean plus 1 times the standard deviation). In statistical notation, this is represented as: $\mu \pm \sigma$.

About 95% of the values lie within 2 standard deviations of the mean (or between the mean minus 2 times the standard deviation, and the mean plus 2 times the standard deviation). The statistical notation for this is: $\mu \pm 2\sigma$.

Almost all (99.7%) of the values lie within 3 standard deviations of the mean (or between the mean minus 3 times the standard deviation and the mean plus 3 times the standard deviation). Statisticians use the following notation to represent this: $\mu \pm 3\sigma$.

| range | fraction in range | expected frequency outside range | approximate frequency for daily event |
|---|---|---|---|
| $\mu \pm 1\sigma$ | 0.682689492137 | 1 in 3 | twice a week |
| $\mu \pm 2\sigma$ | 0.954499736104 | 1 in 22 | monthly |
| $\mu \pm 3\sigma$ | 0.997300203937 | 1 in 370 | yearly |
| $\mu \pm 4\sigma$ | 0.999936657516 | 1 in 15,787 | every 60 years (once in a lifetime) |
| $\mu \pm 5\sigma$ | 0.999999426697 | 1 in 1,744,278 | every 5,000 years (once in history) |
| $\mu \pm 6\sigma$ | 0.999999998027 | 1 in 506,842,372 | every 1.5 million years (essentially never) |

## PRINCIPLES OF SIX SIGMA

These principles can be extracted from texts on Six Sigma:

1. *Senior executive support.* Note the distinction between support, required for Six Sigma, and leadership, required for TQM.

2. *Top-down training.* As in any quality management improvement effort, the need for training must be evaluated, and enough resources provided.
3. *Include the voice of the customer.* This is a reminder to make sure that improvements really benefit the customer so that we avoid meaningless change or change that goes in the wrong direction because it is based on what we think the customer wants.
4. *Create an infrastructure to support success.* The organization will need a structure that integrates Six Sigma methods into processes and allows discoveries through Six Sigma analysis to lead to process change.
5. *Develop short-term projects with specific goals.* This is perhaps Six Sigma's most significant innovation. While some TQM companies naturally discovered the value of setting goals and deadlines, the project-oriented approach became a specific component of Six Sigma. Projects can have both minimum goals and *stretch targets* which motivate the team to think outside the box.
6. *Focus on process improvement.* Just because Six Sigma uses projects to achieve results does not mean that the end of the project is the end of the improvement. Project definition is often based on an evaluation of the process identifying defined, measurable elements that are *critical to quality (CTQ).* Project results are usually internal changes—process improvements that should be maintained by ongoing Six Sigma quality control.
7. *Clear and consistent methodology.* Although there are many variations of Six Sigma, a very consistent approach must be developed by each business.
8. *Decisions based on fact and data.* Six Sigma reasserts the importance of an empirical basis for decisions, just like every quality management movement since Taylor in 1911. Greg Brue, in *Six Sigma for Managers* (2002) emphasizes this with these directives: "Ask questions. Challenge answers. Put assumptions to the test. Confront conventions."
9. *Focus on people and processes.* Six Sigma realizes that our team is a corporate asset we need to invest in, and that team can only benefit the company if it can improve processes by defining CTQ elements that make changes to quality, time, or cost in business processes, products, services, and the bottom line.

## SIX SIGMA METHODOLOGY

### DMAIC

The core of Six Sigma methodology is DMAIC, a minor modification of PDCA which, when spelled out, looks like this:

1. *Define.* We need to turn customer requirements or executive directives for improvements into clearly defined goals, and use a project charter to define the project's purpose; business needs objectives, stakeholders, team members, and sponsor.
2. *Measure.* In this stage, processes and CTQ factors are identified, and the current situation—our starting point for the project—is defined. Logical elements of factors are defined, establishing the factors critical to the success of significant business measures. Processes are defined in such a way as to allow effective statistical measurement, and the initial measurements are made.

3. *Analyze.* We then analyze work processes to identify improvements. There are three main areas to analyze:
   - *Value stream analysis* is borrowed from lean manufacturing. The focus is on eliminating waste, especially wasted time, by eliminating unnecessary steps and improving poorly designed steps.
   - *Analyze sources of variation* using statistical process control techniques.
   - *Determine process drivers,* that is, figure out which inputs or variables change the CTQ elements of a process in key ways. This is done through advanced statistical techniques such as regression analysis, and by designing and performing experiments.
4. *Improve.* First, we define a new process that we think will be better than the current process. Then we evaluate its benefits and look closely at how it might fail so that we don't make things worse. Then, with executive approval, we implement the new process, improving the way work is done. Lastly, we verify that the new process is working. If it fails, we either fix it or roll back to the process we started with.
5. *Control.* To maintain control of the new process: we document the process; we eliminate sources of human error; we provide updated training; and, we bring the new process under statistical process control by updating control procedures and eliminating special causes of variation. When the new process is stable, we document the actual business value achieved. If goals were not met, we begin the DMAIC cycle over again as corrective action. We create a lessons learned document to assist with continuous improvement.

## DMADV

The basic method consists of the following five steps:

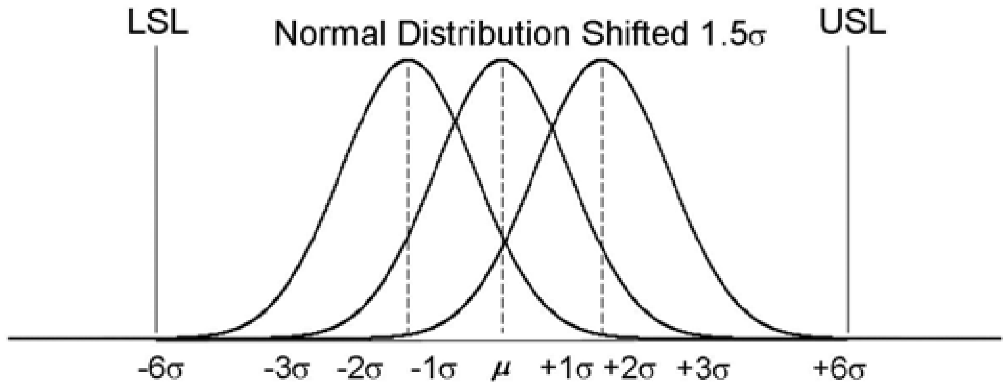
- ***D**efine* design goals that are consistent with customer demands and the enterprise strategy.
- ***M**easure* and identify CTQs (characteristics that are **C**ritical **T**o **Q**uality), product capabilities, production process capability, and risks.
- ***A**nalyze* to develop and design alternatives, create a high-level design and evaluate design capability to select the best design.
- ***D**esign* details, optimize the design, and plan for design verification. This phase may require simulations.
- ***V**erify* the design, set up pilot runs, implement the production process and hand it over to the process owners.

DMADV is also known as DFSS, an abbreviation of "**D**esign **F**or **S**ix **S**igma".

## WHY SIX SIGMA = 4.5 SIGMA

It all started at Motorola. An engineer named Bill Smith—considered the father of Six Sigma—found that, at Motorola, internal quality levels of statistical Six Sigma—two defects per billion opportunities—resulted in external failure rates (customer quality levels) around 4.5 sigma—seven thousand defects per billion opportunities, or seven defects per million opportunities. He called this the *1.5 sigma shift,* and attributed it to a difference between short-term internal QC measurements and long-term product results.

If his investigation into the cause of the 1.5 sigma shift has ever been published outside of Motorola or verified, I have been unable to find it. The 1.5 sigma shift may be rooted in a fundamental statistical principle. If so, it would be nice to understand that principle and how it applies in different settings. It may be a rule of thumb that applied only at Motorola, or only in electronics manufacturing, or only in manufacturing and not in service industries. And we simply don't know.




| Spec limit | Percent | Defective PPM |
|---|---|---|
| +/- 1 sigma | 30.23 | 697700 |
| +/- 2 sigma | 69.13 | 308700 |
| +/- 3 sigma | 93.32 | 66810 |
| +/- 4 sigma | 99.3790 | 6210 |
| +/- 5 sigma | 99.97670 | 233 |
| +/- 6 sigma | 99.9996600 | 3.4 |