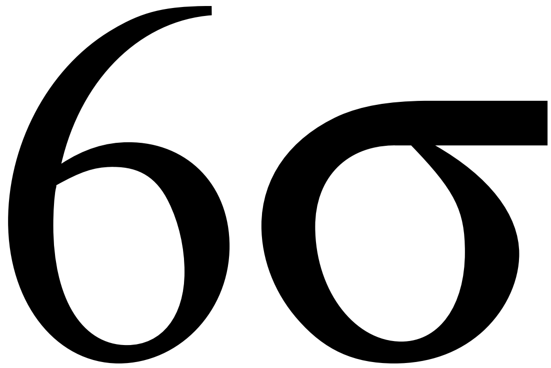
Six Sigma

For other uses, see Sigma 6.

Six Sigma is a set of techniques and tools for process improvement. It was introduced by engineer Bill Smith while working at Motorola in 1986.[1][2] Jack Welch made it central to his business strategy at General Electric in 1995.[3] Today, it is used in many industrial sectors.[4]



The common Six Sigma symbol

Six Sigma seeks to improve the quality of the output of a process by identifying and removing the causes of defects and minimizing variability in manufacturing and business processes. It uses a set of quality management methods, mainly empirical, statistical methods, and creates a special infrastructure of people within the organization, who are experts in these methods. Each Six Sigma project carried out within an organization follows a defined sequence of steps and has specific value targets, for example: reduce process cycle time, reduce pollution, reduce costs, increase customer satisfaction, and increase profits.

The term *Six Sigma* (capitalized because it was written that way when registered as a Motorola trademark on December 28, 1993) originated from terminology associated with statistical modeling of manufacturing processes. The maturity of a manufacturing process can be described by a *sigma* rating indicating its yield or the percentage of defect-free products it creates. A six sigma process is one in which 99.99966% of all opportunities to produce some feature of a part are statistically expected to be free of defects (3.4 defective features per million opportunities). Motorola set a goal of “six sigma” for all of its manufacturing operations, and this goal became a by-word for the management and engineering practices used to achieve it.

1 Doctrine

Six Sigma doctrine asserts:

- Continuous efforts to achieve stable and predictable process results (e.g. by reducing process variation) are of vital importance to business success.
- Manufacturing and business processes have characteristics that can be defined, measured, analyzed, improved, and controlled.
- Achieving sustained quality improvement requires commitment from the entire organization, particularly from top-level management.

Features that set Six Sigma apart from previous quality-improvement initiatives include:

- A clear focus on achieving measurable and quantifiable financial returns from any Six Sigma project.
- An increased emphasis on strong and passionate management leadership and support.
- A clear commitment to making decisions on the basis of verifiable data and statistical methods, rather than assumptions and guesswork.

The term “six sigma” comes from statistics and is used in statistical quality control, which evaluates process capability. Originally, it referred to the ability of manufacturing processes to produce a very high proportion of output within specification. Processes that operate with “six sigma quality” over the short term are assumed to produce long-term defect levels below 3.4 defects per million opportunities (DPMO).[5][6] Six Sigma’s implicit goal is to improve all processes, but not to the 3.4 DPMO level necessarily. Organizations need to determine an appropriate sigma level for each of their most important processes and strive to achieve these. As a result of this goal, it is incumbent on management of the organization to prioritize areas of improvement.

“Six Sigma” was registered June 11, 1991 as U.S. Service Mark 1,647,704. In 2005 Motorola attributed over US$17 billion in savings to Six Sigma.[7]

Other early adopters of Six Sigma include Honeywell (today’s Honeywell is the result of a “merger of equals” of Honeywell and Allied Signal in 1999) and General Electric, where Jack Welch introduced the method.[8] By the late 1990s, about two-thirds of the Fortune 500 organizations had begun Six Sigma initiatives with the aim of reducing costs and improving quality.[9]

In recent years, some practitioners have combined Six Sigma ideas with lean manufacturing to create a methodology named Lean Six Sigma.[10] The Lean Six Sigma methodology views lean manufacturing, which addresses process flow and waste issues, and Six Sigma, with its focus on variation and design, as complementary disciplines aimed at promoting “business and operational excellence”.[10] Companies such as GE,[11] Verizon, GENPACT, and IBM use Lean Six Sigma to focus transformation efforts not just on efficiency but also on growth. It serves as a foundation for innovation throughout the organization, from manufacturing and software development to sales and service delivery functions.

The International Organization for Standardization (ISO) has published in 2011 the first standard “ISO 13053:2011” defining a Six Sigma process.[12] Other “standards” are created mostly by universities or companies that have so-called first-party certification programs for Six Sigma.

2 Difference between related concepts

Lean management and Six Sigma are two concepts which share similar methodologies and tools. Both programs are of Japanese origin, but they are two different programs. Lean management is focused on eliminating waste and ensuring efficiency while Six Sigma’s focus is on eliminating defects and reducing variability.

3 Methodologies

Six Sigma projects follow two project methodologies inspired by Deming's Plan-Do-Check-Act Cycle. These methodologies, composed of five phases each, bear the acronyms DMAIC and DMADV.[9]

- DMAIC (“duh-may-ick”, /dʌ.ˈmeɪ.ɪk/) is used for projects aimed at improving an existing business process.[9]
- DMADV (“duh-mad-vee”, /dʌ.ˈmæd.vi/) is used for projects aimed at creating new product or process designs.[9]

3.1 DMAIC

Main article: DMAIC

The DMAIC project methodology has five phases:

The five steps of DMAIC

- ***Define*** the system, the voice of the customer and their requirements, and the project goals, specifically.
- ***Measure*** key aspects of the current process and collect relevant data; calculate the 'as-is' Process Capability.
- ***Analyze*** the data to investigate and verify cause-and-effect relationships. Determine what the relationships are, and attempt to ensure that all factors have been considered. Seek out root cause of the defect under investigation.
- ***Improve*** or optimize the current process based upon data analysis using techniques such as design of experiments, poka yoke or mistake proofing, and standard work to create a new, future state process. Set up pilot runs to establish process capability.
- ***Control*** the future state process to ensure that any deviations from the target are corrected before they result in defects. Implement control systems such as statistical process control, production boards, visual workplaces, and continuously monitor the process. This process is repeated until the desired quality level is obtained.

Some organizations add a ***Recognize*** step at the beginning, which is to recognize the right problem to work on, thus yielding an RDMAIC methodology.[13]

3.2 DMADV or DFSS

The five steps of DMADV

Main article: DFSS

The DMADV project methodology, known as DFSS ("**D**esign **F**or **S**ix **S**igma”),[9] features five phases:

- ***Define*** design goals that are consistent with customer demands and the enterprise strategy.

- ***Measure*** and identify CTQs (characteristics that are **C**ritical **T**o **Q**uality), measure product capabilities, production process capability, and measure risks.
- ***Analyze*** to develop and design alternatives
- ***Design*** an improved alternative, best suited per analysis in the previous step
- ***Verify*** the design, set up pilot runs, implement the production process and hand it over to the process owner(s).

3.3 Quality management tools and methods

Within the individual phases of a DMAIC or DMADV project, Six Sigma utilizes many established quality-management tools that are also used outside Six Sigma. The following table shows an overview of the main methods used.

- 5 Whys
- Statistical and fitting tools
  - Analysis of variance
  - General linear model
  - ANOVA Gauge R&R
  - Regression analysis
  - Correlation
  - Scatter diagram
  - Chi-squared test
- Axiomatic design
- Business Process Mapping/Check sheet
- Cause & effects diagram (also known as fishbone or Ishikawa diagram)
- Control chart/Control plan (also known as a swimlane map)/Run charts
- Cost-benefit analysis
- CTQ tree
- Design of experiments/Stratification
- Histograms/Pareto analysis/Pareto chart
- Pick chart/Process capability/Rolled throughput yield
- Quality Function Deployment (QFD)
- Quantitative marketing research through use of Enterprise Feedback Management (EFM) systems
- Root cause analysis
- SIPOC analysis (**S**uppliers, **I**nputs, **P**rocess, **O**utputs, **C**ustomers)
- COPIS analysis (Customer centric version/perspective of SIPOC)
- Taguchi methods/Taguchi Loss Function
- Value stream mapping

4 Implementation roles

One key innovation of Six Sigma involves the absolute "professionalizing" of quality management functions. Prior to Six Sigma, quality management in practice was largely relegated to the production floor and to statisticians in a separate quality department. Formal Six Sigma programs adopt a kind of elite ranking terminology (similar to some martial arts systems, like Kung-Fu and Judo) to define a hierarchy (and special career path) that includes all business functions and levels.

Six Sigma identifies several key roles for its successful implementation.[14]

- *Executive Leadership* includes the CEO and other members of top management. They are responsible for setting up a vision for Six Sigma implementation. They also empower the other role holders with the freedom and resources to explore new ideas for breakthrough improvements by transcending departmental barriers and overcoming inherent resistance to change.[15]
- *Champions* take responsibility for Six Sigma implementation across the organization in an integrated manner. The Executive Leadership draws them from upper management. Champions also act as mentors to Black Belts.
- *Master Black Belts*, identified by Champions, act as in-house coaches on Six Sigma. They devote 100% of their time to Six Sigma. They assist Champions and guide Black Belts and Green Belts. Apart from statistical tasks, they spend their time on ensuring consistent application of Six Sigma across various functions and departments.
- *Black Belts* operate under Master Black Belts to apply Six Sigma methodology to specific projects. They devote 100% of their valued time to Six Sigma. They primarily focus on Six Sigma project execution and special leadership with special tasks, whereas Champions and Master Black Belts focus on identifying projects/functions for Six Sigma.
- *Green Belts* are the employees who take up Six Sigma implementation along with their other job responsibilities, operating under the guidance of Black Belts.

Special training is needed[16] for all of these practitioners to ensure that they follow the methodology and use the data-driven approach correctly. This training is very important.

Some organizations use additional belt colours, such as *Yellow Belts*, for employees that have basic training in Six Sigma tools and generally participate in projects and "White belts" for those locally trained in the concepts but do not participate in the project team. "Orange belts" are also mentioned to be used for special cases.[17]

4.1 Certification

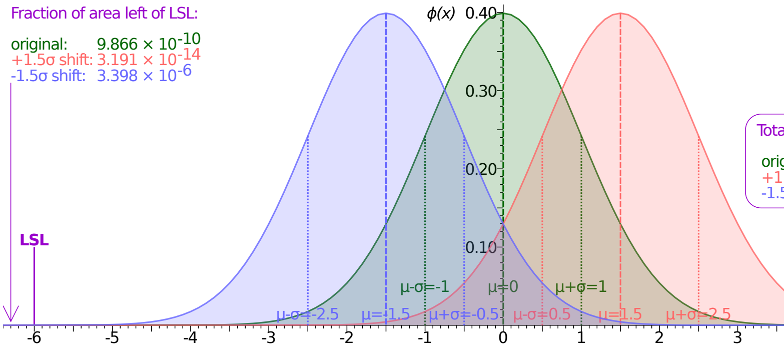
Main article: List of Six Sigma certification organizations

General Electric and Motorola developed certification programs as part of their Six Sigma implementation, verifying individuals' command of the Six Sigma methods at the relevant skill level (Green Belt, Black Belt etc.). Following this approach, many organizations in the 1990s started offering Six Sigma certifications to their employees.[9][18] Criteria for Green Belt and Black Belt certification vary; some companies simply require participation in a course and a Six Sigma project.[18] There is no standard certification body, and different certification services are offered by various quality associations and other providers against a fee.[19][20] The American Society for Quality for example requires Black Belt applicants to pass a written exam and to provide a signed affidavit stating that they have completed two projects or one project combined with three years' practical experience in the body of knowledge.[18][21]

5 Etymology of "six sigma process"

The term "six sigma process" comes from the notion that if one has six standard deviations between the process mean and the nearest specification limit, as shown in the graph, practically no items will fail to meet specifications.[5] This is based on the calculation method employed in process capability studies.

Capability studies measure the number of standard deviations between the process mean and the nearest specification limit in sigma units, represented by the Greek letter σ (sigma). As process standard deviation goes up, or the mean of the process moves away from the center of the tolerance, fewer standard deviations will fit between the mean and the nearest specification limit, decreasing the sigma number and increasing the likelihood of items outside specification. One should also note that calculation of Sigma levels for a process data is independent of the data being normally distributed. In one of the criticisms to Six Sigma, practitioners using this approach spend a lot of time transforming data from non-normal to normal using transformation techniques. It must be said that Sigma levels can be determined for process data that has evidence of non-normality.[5]



of the normal distribution, which underlies the statistical assumptions of the Six Sigma model. The Greek letter σ (sigma) marks the distance on the horizontal axis between the mean, μ, and the curve's inflection point. The greater this distance, the greater is the spread of values encountered. For the green curve shown above, μ = 0 and σ = 1. The upper and lower specification limits (USL and LSL, respectively) are at a distance of 6σ from the mean. Because of the properties of the normal distribution, values lying that far away from the mean are extremely unlikely. Even if the mean were to move right or left by 1.5σ at some point in the future (1.5 sigma shift, coloured red and blue), there is still a good safety cushion. This is why Six Sigma aims to have processes where the mean is at least 6σ away from the nearest specification limit.

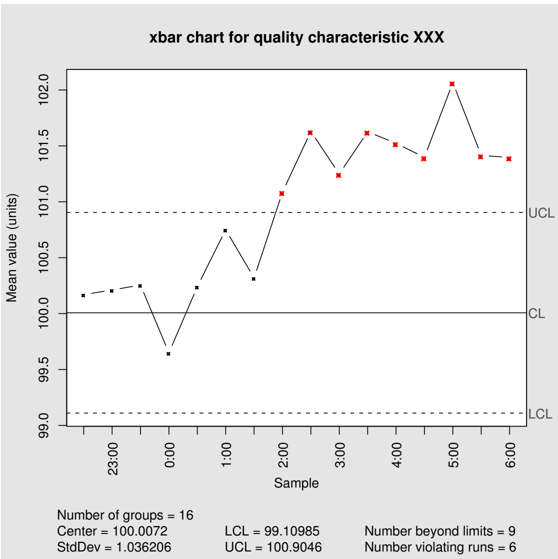
6 Role of the 1.5 sigma shift

Experience has shown that processes usually do not perform as well in the long term as they do in the short term.[5] As a result, the number of sigmas that will fit between the process mean and the nearest specification limit may well drop over time, compared to an initial short-term study.[5] To account for this real-life increase in process variation over time, an empirically based 1.5 sigma shift is introduced into the calculation.[5][22] According to this idea, a process that fits 6 sigma between the process mean and the nearest specification limit in a short-term study will in the long term fit only 4.5 sigma – either because the process mean will move over time, or because the long-term standard deviation of the process will be greater than that observed in the short term, or both.[5]

Hence the widely accepted definition of a six sigma process is a process that produces 3.4 defective parts per million opportunities (DPMO). This is based on the fact that a process that is normally distributed will have 3.4 parts per million outside the limits, when the limits are six sigma from the "original" mean of zero and the process mean is then shifted by 1.5 sigma (and therefore, the six sigma limits are no longer symmetrical about the mean).[5] The former six sigma distribution, when under the effect of the 1.5 sigma shift, is commonly referred to as a 4.5 sigma process. However, it should be noted that the failure rate of a six sigma distribution with the mean shifted 1.5 sigma is not equivalent to the failure rate of a 4.5 sigma process with the mean centered on zero.[5] This allows for the fact that special causes may result in a deterioration in process performance over time and is designed to prevent underestimation of the defect levels likely to be encountered in real-life operation.[5]

The role of the sigma shift is mainly academic. The purpose of six sigma is to generate organizational performance improvement. It is up to the organization to determine, based on customer expectations, what the appropriate sigma level of a process is. The purpose of the sigma value is as a comparative figure to determine whether a process is improving, deteriorating, stagnant or non-competitive with others in the same business. Six sigma (3.4 DPMO) is not the goal of all processes.

6.1 Sigma levels



A control chart depicting a process that experienced a 1.5 sigma drift in the process mean toward the upper specification limit starting at midnight. Control charts are used to maintain 6 sigma quality by signaling when quality professionals should investigate a process to find and eliminate special-cause variation.

See also: Three sigma rule

The table below gives long-term DPMO values corresponding to various short-term sigma levels.[23][24]

These figures assume that the process mean will shift by 1.5 sigma toward the side with the critical specification limit. In other words, they assume that after the initial study determining the short-term sigma level, the long-term C_{pk} value will turn out to be 0.5 less than the short-term C_{pk} value. So, for example, the DPMO figure given for 1 sigma assumes that the long-term process mean will be 0.5 sigma beyond the specification limit (C_{pk} = –0.17), rather than 1 sigma within it, as it was in the short-term study (C_{pk} = 0.33). Note that the defect percentages indicate only defects exceeding the specification limit to which the process mean is nearest. Defects beyond the far specification limit are not included in the percentages.

7 Software

Main article: List of Six Sigma software packages

8 Application

Main article: List of Six Sigma companies

Six Sigma mostly finds application in large organizations.[25] An important factor in the spread of Six Sigma was GE's 1998 announcement of $350 million in savings thanks to Six Sigma, a figure that later grew to more than $1 billion.[25] According to industry consultants like Thomas Pyzdek and John Kullmann, companies with fewer than 500 employees are less suited to Six Sigma implementation or need to adapt the standard approach to make it work for them.[25] Six Sigma however contains a large number of tools and techniques that work well in small to mid-size organizations. The fact that an organization is not big enough to be able to afford Black Belts does not diminish its abilities to make improvements using this set of tools and techniques. The infrastructure described as necessary to support Six Sigma is a result of the size of the organization rather than a requirement of Six Sigma itself.[25]

9 Criticism

9.1 Lack of originality

Quality expert Joseph M. Juran described Six Sigma as "a basic version of quality improvement", stating that "there is nothing new there. It includes what we used to call facilitators. They've adopted more flamboyant terms, like belts with different colors. I think that concept has merit to set apart, to create specialists who can be very helpful. Again, that's not a new idea. The American Society for Quality long ago established certificates, such as for reliability engineers."[26]

9.2 Inadequate for complex manufacturing

Quality expert Philip B. Crosby pointed out that the Six Sigma standard doesn't go far enough[27]—customers deserve defect-free products every time. For example, under the Six Sigma standard, semiconductors which require the flawless etching of millions of tiny circuits onto a single chip are all 100% unusable.[28]

9.3 Role of consultants

The use of “Black Belts” as itinerant change agents has fostered an industry of training and certification. Critics have argued there is overselling of Six Sigma by too great a number of consulting firms, many of which claim expertise in Six Sigma when they have only a rudimentary understanding of the tools and techniques involved or the markets or industries in which they are acting.[29]

9.4 Potential negative effects

A *Fortune* article stated that “of 58 large companies that have announced Six Sigma programs, 91 percent have trailed the S&P 500 since”. The statement was attributed to “an analysis by Charles Holland of consulting firm Qualpro (which espouses a competing quality-improvement process)".[30] The summary of the article is that Six Sigma is effective at what it is intended to do, but that it is “narrowly designed to fix an existing process” and does not help in “coming up with new products or disruptive technologies.”[31][32]

9.4.1 Over-reliance on statistical tools

A more direct criticism is the “rigid” nature of Six Sigma with its over-reliance on methods and tools. In most cases, more attention is paid to reducing variation and searching for any significant factors and less attention is paid to developing robustness in the first place (which can altogether eliminate the need for reducing variation).[33] The extensive reliance on significance testing and use of multiple regression techniques increases the risk of making commonly unknown types of statistical errors or mistakes. A possible consequence of Six Sigma’s array of P-value misconceptions is the false belief that the probability of a conclusion being in error can be calculated from the data in a single experiment without reference to external evidence or the plausibility of the underlying mechanism.[34] One of the most serious but all-too-common misuses of inferential statistics is to take a model that was developed through exploratory model building and subject it to the same sorts of statistical tests that are used to validate a model that was specified in advance.[35]

Another comment refers to the often mentioned Transfer Function, which seems to be a flawed theory if looked at in detail.[36] Since significance tests were first popularized many objections have been voiced by prominent and respected statisticians. The volume of criticism and rebuttal has filled books with language seldom used in the scholarly debate of a dry subject.[37][38][39][40] Much of the first criticism was already published more than 40 years ago. Refer to: Statistical hypothesis testing#Criticism for details.

Articles featuring critics have appeared in the November–December 2006 issue of *USA Army Logistician* regarding Six-Sigma: “The dangers of a single paradigmatic orientation (in this case, that of technical rationality) can blind us to values associated with double-loop learning and the learning organization, organization adaptability, workforce creativity and development, humanizing the workplace, cultural awareness, and strategy making.”[41]

Nassim Nicholas Taleb consider risk managers little more than “blind users” of statistical tools and methods.[42] He states that statistics is fundamentally incomplete as a field as it cannot predict the risk of rare events — something Six Sigma is specially concerned with. Furthermore, errors in prediction are likely to occur as a result of ignorance for or distinction between epistemic and other uncertainties. These errors are the biggest in time variant (reliability) related failures.[43]

9.4.2 Stifling creativity in research environments

A *BusinessWeek* article says that James McNerney's introduction of Six Sigma at 3M had the effect of stifling creativity and reports its removal from the research function. It cites two Wharton School professors who say that Six Sigma leads to incremental innovation at the expense of blue skies research.[44] This phenomenon is further explored in the book *Going Lean*, which describes a related approach known as lean dynamics and provides data to show that Ford's “6 Sigma” program did little to change its fortunes.[45]

According to an article by John Dodge, editor in chief of *Design News*, use of Six Sigma is inappropriate in a research environment. Dodge states[46] “excessive metrics, steps, measurements and Six Sigma’s intense focus on reducing variability water down the discovery process. Under Six Sigma, the free-wheeling nature of brainstorming and the serendipitous side of discovery is stifled.” He concludes “there’s general agreement that freedom in basic or pure research is preferable while Six Sigma works best in incremental innovation when there’s an expressed commercial goal.”

9.5 Lack of systematic documentation

One criticism voiced by Yasar Jarrar and Andy Neely from the Cranfield School of Management's Centre for Business Performance is that while Six Sigma is a powerful approach, it can also unduly dominate an organization's culture; and they add that much of the Six Sigma literature – in a remarkable way (six-sigma claims to be evidence, scientifically based) – lacks academic rigor:

> One final criticism, probably more to the Six Sigma literature than concepts, relates to the evidence for Six Sigma's success. So far, documented case studies using the Six Sigma methods are presented as the strongest evidence for its success. However, looking at these documented cases, and apart from a few that are detailed from the experience of leading organizations like GE and Motorola, most cases are not documented in a systemic or academic manner. In fact, the majority are case studies illustrated on websites, and are, at best, sketchy. They provide no mention of any specific Six Sigma methods that were used to resolve the problems. It has been argued that by relying on the Six Sigma criteria, management is lulled into the idea that something is being done about quality, whereas any resulting improvement is accidental (Latzko 1995). Thus, when looking at the evidence put forward for Six Sigma success, mostly by consultants and people with vested interests, the question that begs to be asked is: are we making a true improvement with Six Sigma methods or just getting skilled at telling stories? Everyone seems to believe that we are making true improvements, but there is some way to go to document these empirically and clarify the causal relations.
>
> — [33]

9.6 1.5 sigma shift

The statistician Donald J. Wheeler has dismissed the 1.5 sigma shift as "goofy" because of its arbitrary nature.[47] Its universal applicability is seen as doubtful.

The 1.5 sigma shift has also become contentious because it results in stated "sigma levels" that reflect short-term rather than long-term performance: a process that has long-term defect levels corresponding to 4.5 sigma performance is, by Six Sigma convention, described as a "six sigma process."[5][48] The accepted Six Sigma scoring system thus cannot be equated to actual normal distribution probabilities for the stated number of standard deviations, and this has been a key bone of contention over how Six Sigma measures are defined.[48] The fact that it is rarely explained that a "6 sigma" process will have long-term defect rates corresponding to 4.5 sigma performance rather than actual 6 sigma performance has led several commentators to express the opinion that Six Sigma is a confidence trick.[5]

10 See also

- Design for Six Sigma
- DMAIC
- Kaizen – a philosophical focus on continuous improvement of processes
- Lean Six Sigma
- Lean Manufacturing
- Management fad
- Total productive maintenance
- Total quality management
- W. Edwards Deming

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