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SIX SIGMA: A BASIC OVERVIEW

In the nearly 30 years since it was first introduced, Six Sigma[1] has evolved to mean different things in different circumstances and in different organizations, so that now it is difficult to identify a single, universally accepted definition. That said, however, Six Sigma always has been and remains a rigorous, data-based approach to improving the performance of an organization.

Motorola, Inc., developed Six Sigma in the early 1980s, but it was over the ensuing years—as other Fortune 500 companies, like General Electric under Jack Welch, adopted Six Sigma and reported on its significant benefits in a variety of settings—that the Six Sigma approach to performance improvement really caught on.

The purpose of this note is to provide a basic overview of Six Sigma by explaining its underlying principles and most commonly utilized methods while providing a brief review of its history. Finally, the note will provide a brief summary of a Six Sigma case study illustrating the practical application of Six Sigma.

What Exactly Is Six Sigma?

As Six Sigma has gained in popularity, its definition has become more and more diluted, so that today it appears as if virtually any quality-improvement process can be called Six Sigma, and few seem the wiser for it.

For practical purposes, however, Six Sigma can be defined as a specific methodology to develop and implement quality improvements in an organization's critical processes by rigorously measuring and identifying variations from customer specifications in those processes and adjusting them or creating entirely new processes to keep variations at an acceptable level.

[1] Six Sigma is a registered trademark of Motorola, Inc.

This technical note was prepared by Alan Zimmerman, Research Assistant, under the supervision of Robert D. Landel, the Henry E. McWane Professor of Business Administration. It was written as a basis for class discussion rather than to illustrate effective or ineffective handling of an administrative situation.

In answer to the question of what makes Six Sigma unique, General Electric says:

> Six Sigma, of course, did not invent the concept of quality improvement. Rather, Six Sigma's innovation was to focus on the variation in defects as a metric for defining quality and to provide an objective and mathematical basis for defining the critical processes that require improvement.
>
> Often, our inside-out view of the business is based on average or mean-based measures of our recent past. Customers don't judge us on averages; they feel the variance in each transaction, in each product we ship. Six Sigma focuses first on reducing process variation and then on improving the process capability.
>
> Customers value consistent, predictable business processes that deliver world-class levels of quality. This is what Six Sigma strives to produce.[2]

Specifically, Six Sigma seeks to focus an organization on

- defining customer/user requirements,
- aligning processes to meet those requirements,
- using metrics to minimize variations in processes,
- rapidly and permanently improving processes.

The name Six Sigma is derived from the Greek letter *sigma* (denoted by lowercase *s*), which is a statistics term used to define standard deviation or variability from a mean. Because a better-quality process or set of processes is less likely to produce a defect in any given product or operation, the higher the quality, the higher the *sigma*—in other words, the fewer variations from customer specifications.

Six Sigma is a level of quality producing a frequency of defects per million operations (DPMO) that is six standard deviations from a given mean (typically defined as the average of the upper and lower limits of customer specifications for a given product or operation) based on a normalized distribution.[3] An operation in this context is defined as any activity that is critical to an organization's mission, such as manufacturing a component, processing a form, or understanding a customer's complaint.

[2] General Electric, *What Is Six Sigma? The Roadmap to Customer Impact*.

[3] The creators of Six Sigma at Motorola thought 6s was the best possible performance. Because DPMO at each *sigma* is calculated exponentially, 7s is generally not considered to be a statistically meaningful number. That said, however, there are arguably processes that exceed Six Sigma.

Mathematically, 6s translates into 3.4 DPMO, as shown in **Table 1**:[4]

Table 1. DPMO calculations.

Sigma	DPMO	Percentage of Successful Operations
1	691,462	30.9%
2	308,538	69.1%
3	66,807	93.3%
4	6,210	99.4%
5	233	99.98%
6	3.4	99.99966%

What constitutes an acceptable level of quality for a business? Obviously, that depends on numerous factors, but any business operating at less than 3s (93.3% of its operations are successful) is generally considered unsustainable. A quality level of 4s (99.4% of its operations are successful) might be quite an acceptable, even superior, performance for a fast-food restaurant, while that same level might be inadequate for a commercial airline.

Implementation of Six Sigma

The principal methodologies used to implement Six Sigma are the DMAIC and DMADV models—acronyms, respectively, for Define, Measure, Analyze, Improve, and Control, and Define, Measure, Analyze, Design, and Verify.[5] Each of these components is roughly defined as follows:

- *Define*: Understand customers' needs and develop both minimum and ideal specifications to meet those needs. Methods can include traditional means to solicit customer feedback, such as surveys or personal visits, as well as brainstorming and historical data.
- *Measure*: List and describe all processes critical to manufacturing goods or providing services consistent with specifications. Develop or use available statistical data, such as

[4] A 3.4 DPMO reflects long-term process capability. At short-term process capability, a 6s level of quality would actually produce only .002 DPMO, based on a normalized distribution. Owing to the nature of processes, however, shifts and drifts naturally occur in the mean of the distribution of a component value over time because of such factors as changes in personnel and suppliers, movements of machinery, wear and tear on machinery, etc. As a result, the long-term performance for a single process has been calculated as likely to deviate from its natural center by approximately 1.5s at any given point in time.

[5] Typically, DMAIC is used to improve existing processes, while DMADV is used to create new processes. Other processes, beyond the scope of this note, have been developed for Six Sigma methodologies, including DMADOV (Define, Measure, Analyze, Design, Optimize, Verify), DMEDI (Design, Measure, Explore, Develop, Implement), IDOV (Identify, Design, Optimize, Validate), and I2DOV (Invent, Innovate, Develop, Optimize, Validate).

historical information, yield reports, analysis reports, or production data, to define the baseline level of performance and determine potential problem areas.

- *Analyze*: Comprehend the reasons behind defects by narrowing the potential list of problems to a manageable number and specifically determining the causes of variation in products or services, determining the limitations of the processes to ensure that they are capable of achieving the desired objective, and identifying ways to narrow the gap between baseline and desired performance.
- *Improve* (Design): Develop specific solutions to problems, plan and conduct experiments implementing those solutions, and measure the results, modifying the solutions, as appropriate, as the experiments proceed.
- *Control* (Verify): Establish that the new system is stable, within acceptable variation limits, and predicable. Institutionalize the new system through revised procedures, policies, and other management systems, and develop and implement ongoing measurements to monitor and gauge performance on an ongoing basis.

Six Sigma requires buy-in and properly trained individuals at all levels, beginning at the very top. In the absence of senior executive support, implementers of Six Sigma projects will lack the necessary clout and credibility to succeed. Trained implementers of Six Sigma projects are as follows:[6]

- *Black Belt*: Six Sigma experts highly skilled in the application of rigorous statistical tools and methodologies to drive business-process improvement, Black Belts who have significant experience and achieve positive results can reach the status of a Master Black Belt. Black Belts are able to tackle most complex projects and train other Black Belts and Green Belts, and can be in-house or consultants brought in from outside an organization.
- *Champion*: Charged with the day-to-day responsibility for improving the business process, Champions are responsible for ensuring that the project team has the required resources.
- *Green Belt*: Trained in the methodology and tools needed to work effectively on a project, Green Belts typically work under the direction of Black Belts at the workplace level to ensure the implementation of process changes but may handle less complex projects on their own.
- *Yellow Belt*: Trained in Six Sigma techniques, perhaps as part of company-wide training, these employees are not expected to actively engage in quality-improvement activities.

[6] These definitions are drawn from Motorola University, with the exception of Yellow Belt, which is drawn from isixsigma.com, a Web site devoted to Six Sigma.

History and Evolution of Six Sigma

Six Sigma was developed at Motorola in the mid-1980s. Two Motorola engineers, Mike Harry and Bill Smith, are generally acknowledged as its creators, although Six Sigma is actually based on several techniques of quality management that had been known and practiced for decades. It was officially introduced as a long-term quality program at Motorola in January 1987. In 1988, Motorola was among the first recipients of the Malcolm Baldrige National Quality Award.

Over the next several years, Harry sought to leverage Six Sigma throughout Motorola, as well as formalize training in its implementation, so that knowledge could migrate from quality engineers throughout the organization. After a discussion about Six Sigma training with a friend who studied martial arts, Harry hit upon the "belt" nomenclature for designating levels of expertise.

As originally conceived, Six Sigma was a *metric* for improving the quality of manufactured components; in fact, its mathematically based nomenclature represents one of its more significant innovations, namely, the use of a more rigorous standard in which defects are measured per *million* rather than per hundreds or thousands of opportunities. Following its initial successful implementation, Motorola extended Six Sigma to other critical business processes, where it eventually evolved into an improvement *methodology*.

In 1993, Harry moved to Allied Signal, which also adopted Six Sigma. Within six months, the company reported significant improvements in costs and savings. Allied Signal's CEO, Lawrence Bossidy, had once worked under Jack Welch at General Electric, and Welch, impressed with Allied Signal's improvements, invited Bossidy to speak at GE's Corporate Executive Council meeting in 1995. GE then conducted a cost-benefit analysis on Six Sigma implementation. It showed that the company was running at a quality level of 3s to 4s and that Six Sigma could reduce costs by between $7 billion and $10 billion.

In 1996, Welch introduced Six Sigma at GE. A significant step in Six Sigma's evolution at GE was Welch's strong backing and commitment, which included basing executive compensation and advancement, in large part, on the adoption of Six Sigma.

Since then, dozens of companies have implemented Six Sigma, including Bank of America, Caterpillar, and Merrill Lynch. According to the American Society for Quality, 82 of the country's 100 largest corporations have used it.[7] Formal training of Six Sigma specialists, which began at Motorola in the early 1990s, had, within the decade, spawned a cottage industry of training, certification, software tools, and consultancy, not to mention a publishing phenomenon.[7]

As of 2006, Motorola claimed to have reaped approximately $17 billion in savings from Six Sigma projects.[8] But Six Sigma has its detractors as well.

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[7] An Amazon.com search for Six Sigma, for example, yields 3,860 results.

[8] About Motorola University, www.motorola.com/content/0,3071-5801,00.html.

For example, in 2005, the magazine *Fast Company* reported on Six Sigma: "No one disputes the worthiness of Six Sigma's intentions, much less the statistics. But a quick survey of a handful of industries, using product-quality ratings from J. D. Power and Associates, led [us] to believe that while [Jack] Welch may be right that you can't afford not to understand Six Sigma, you can't necessarily afford to use it either."[9]

The article went on to note that even as Xerox touted its Six Sigma credentials, it ranked lower in quality than Canon, Toshiba, and Hewlett-Packard. The article also cited Larson Boats, which had two Six Sigma Black Belts on staff but ranked last among the 11 companies that built express cruisers.

A controversial but widely discussed 2006 study by consultant Charles Holland (who espouses a management philosophy that competes with Six Sigma) found that of 58 large companies that had announced the adoption of Six Sigma, the stock prices of 91% trailed the S&P 500.[10]

The primary objections to Six Sigma are that even as it cuts costs and increases profits, it stifles innovation and can wear down employee morale. Robert Nardelli's tenure as CEO at Home Depot presents an excellent example. Writing about Home Depot in June 2007, *BusinessWeek* claimed:

> Six Sigma was used to streamline the check-out process and strategically place vacuum cleaner displays. But by-products of the program irritated many at the retailer's stores, who thought its constant data measurement and paperwork sapped time given to customers. The bottom line on Nardelli's tenure: Profitability soared, but worker morale dropped and so did consumer sentiment. Home Depot dropped from first to worst among major retailers on the American Customer Satisfaction Index in 2005. [11]

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[9] Martin Kihn, "Six Sigma Stigma," *Fast Company*, September 2005.

[10] Betsy Morris, "New Rule: Look Out, Not In," *Fortune*, July 11, 2006. Holland's methodology, not to mention his conflict of interest, has been strongly critiqued.

[11] Hindo, "Six Sigma: So Yesterday?"

Six Sigma Case Study

Motorola and 3M: Improving the Global Shipment of Semiconductor Products[12]

Background

In 2004, as the price of semiconductors began to fall, Motorola searched for ways to reduce excess costs in its global supply chain as a means to boost margins. In addition, Motorola sought to reduce the possibility of damage to its semiconductor wafers, which had grown progressively thinner and more fragile during transport. The process Motorola eventually adopted would have to be implemented globally among seven fabrication and two assembly/test facilities, as well as among several subcontractors, all spanning a variety of languages and cultures.

Existing packing methods relied on corrugated containers with polyurethane-foam fillers. Wafers were packed vertically. The method was expensive because air-freight charges are based on dimension, not weight, and disposal of the packing materials raised environmental issues that varied from country to country.

Motorola believed a new packing system could address all of these issues and requested proposals from several vendors.

Motorola opted to work with 3M Industrial Services and Solutions Division to develop and implement a new system. The firms decided to apply Six Sigma methodology to the project because both used Six Sigma in manufacturing operations and therefore were familiar with it.

Define

In the define phase, 3M focused on creating a project charter to establish the objectives, financial justifications, and scope of the project and then translating Motorola's objectives into 3M service requirements.

The project's ongoing goals were defined as follows:

- Improving the reliability of wafer transportation
- Eliminating damage
- Reducing freight expense
- Reducing the cost of packing materials
- Increasing productivity
- Improving customer satisfaction

[12] This case study is drawn from 3M Business Development, "Six Sigma–Based Methodology—A Motorola/3M Case Study," *Future Fab International*, www.future-fab.com/documents.asp?d_ID=2308#.

Measure

Motorola's current processes were documented and critical input and output variables were determined. The teams analyzed the input variables through a cause-and-effect matrix to determine key factors that could affect objectives. The cleanliness of each of the packing system's parts, for example, was a key factor in reducing wafer damage during packing and transport.

Analyze

Analysis included reducing the number of output variables, assessing high-risk inputs, and identifying means of eliminating them.

Improve

After testing a variety of Motorola wafers in multiple packing configurations, 3M performed a side-by-side comparison of its proposed solution with Motorola's existing system. Motorola collected extensive data from several fabrication and assembly sites.

The horizontal-wafer shippers ultimately developed by 3M for Motorola allowed wafers to be stacked on one another, with air cushioning protecting the shippers. Four horizontal shippers, each containing 25 wafers, can be placed in each air cushion, which holds them firmly in place. In addition, the shipping components are reusable or, if not reusable, recyclable, making them environmentally friendly.

The system minimizes wafer damage and significantly reduces freight costs.

Control

After understanding each facility's specific requirements and identifying and removing variables, project leaders assigned by 3M and Motorola rolled out the new transport system for use across Motorola's operations, and 3M trained Motorola employees at each site.

Web Sites for Further Reading

i Six Sigma is a comprehensive Six Sigma Web site (www.isixsigma.com).

See the Motorola University Web site (http://www.motorola.com/motorolauniversity.jsp) for Six Sigma at Motorola.

"General Electric—The Roadmap to Customer Impact" describes the company-wide approach to Six Sigma at one of the world's better-known followers of the methodology. The article can be found at http://www.ge.com/sixsigma/SixSigma.pdf.

The American Society for Quality Six Sigma Forum contains excellent downloadable articles (www.asq.org/sixsigma).

Bibliography

3M Business Development. "Six Sigma–Based Methodology—A Motorola/3M Case Study." *Future Fab International* 16 (February 3, 2004), http://www.future-fab.com/documents.asp?d_ID=2308#.

Gale, Sarah. "Building Frameworks for Six Sigma Success—Case Studies—Quality Management Philosophy." *Workforce* (May 2003), http://findarticles.com/p/articles/mi_m0FXS/is_5_82/ai_101531687. See also www.workforce.com.

General Electric. "The Roadmap to Customer Impact," http://www.ge.com/sixsigma/SixSigma.pdf.

Hindo, Brian. "Six Sigma: So Yesterday?" *BusinessWeek* (June 11, 2007).

Kihn, Martin. "Six Sigma Stigma." *Fast Company* (September 2005).

Morris, Betsy. "New Rule: Look Out, Not In." *Fortune* (July 11, 2006).

Motorola University. "Six Sigma in Action," http://www.motorola.com/motorolauniversity.jsp.

Process Quality Associates, Inc. "The Evolution of Six Sigma," http://www.pqa.net/ProdServices/sixsigma/W06002009.html.

Process Quality Associates, Inc. "What Is Six Sigma," http://www.pqa.net/ProdServices/sixsigma/W06001001.html#WhatisSixSigma.

Pyzdek, Thomas. "Motorola's Six Sigma Program." *Quality Digest* (December 1997), http://www.qualitydigest.com/dec97/html/motsix.html.

Simon, Kerry. "DMAIC versus DMADV." *i Six Sigma*, http://www.isixsigma.com/library/content/c001211a.asp.

"Six Sigma." *Wikipedia*, http://en.wikipedia.org/wiki/Six_Sigma.

"six sigma." *businessballs.com*, http://businessballs.com/sixsigma.htm.

"Six Sigma—What Is Six Sigma?" *i Six Sigma*, http://www.isixsigma.com/sixsigma/six_sigma.asp.