

Second Edition

An Introduction to

Six Sigma

& Process Improvement

Evans | Lindsay

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An Introduction to **Six
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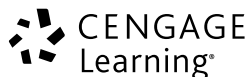
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***An Introduction to Six Sigma @ Process
Improvement, Second Edition***

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P R E F A C E

Six Sigma¹ represents an effective and validated approach in manufacturing and service organizations to improve products, services, and processes. Although Six Sigma brought a new direction to quality and productivity improvement, its underlying tools and philosophy are grounded in the fundamental principles of total quality and continuous improvement that have been used for many decades.

Numerous professional references and trade books have been published promoting Six Sigma tools and various customized spins on the philosophy and implementation process. We wrote this book to provide a succinct and basic introduction to Six Sigma and process improvement concepts in a style and format suitable for use in both undergraduate and graduate courses in operations management, industrial engineering, and related disciplines, as well as in professional development and continuing education short courses. The second edition updates the material in the first edition, with numerous improvements and a stronger emphasis on using Microsoft Excel to implement many of the procedures.

The book's nine chapters are divided logically into three parts: principles of Six Sigma (chapters 1 and 2), Six Sigma DMAIC methodology (chapters 3 to 7), additional topics in Six Sigma (chapters 8 and 9). Because of the close relationship of the Six Sigma DMAIC process to projects and project management, curriculum developers or trainers may wish to combine the content areas of Six Sigma with introductory or advanced concepts of project management in the same course.

Chapter 1, *Foundations of Six Sigma: Principles of Quality Management*, introduces the concept of Six Sigma and traces its development from earlier approaches to quality management. It also lays the foundation for Six Sigma by reviewing basic definitions of quality and the fundamental principles on which quality management philosophies are based. Additionally, Chapter 1 also discusses the links among Six Sigma, business results, and competitive advantage.

Chapter 2, *Principles of Six Sigma*, begins with a discussion of process concepts and systems thinking. We introduce the Six Sigma Body of Knowledge promoted by the American Society for Quality (ASQ), discuss the importance of metrics and measurement in Six Sigma, describe the DMAIC problem-solving methodology that forms the framework for subsequent chapters, and also discuss the growing importance of Six Sigma in service organizations.

¹ Six Sigma is a federally registered trademark and service mark of Motorola, Inc.

Chapter 3, Project Organization, Selection, and Definition, focuses on organizational issues in developing Six Sigma projects and teams, including the role of project management in coordinating projects, skills needed by team members, and team dynamics. Techniques and approaches for selecting appropriate Six Sigma projects are discussed. This chapter also describes the Define phase of DMAIC, focusing on developing high-level process maps and identifying critical-to-quality characteristics of customers.

Chapter 4, Process Measurement, deals with a variety of basic topics associated with the Measure phase of DMAIC, namely, metric selection, data collection, and statistical data summarization. This chapter also discusses metrology and measurement system evaluation and process capability evaluation.

Chapter 5, Process Analysis, emphasizes statistical tools and other valuable methods for analyzing data and identifying root causes in the Analyze phase of DMAIC. This discussion includes a review of probability distributions and basic statistical methods, and the application of process maps, value stream maps, statistical thinking, root cause analysis, and cause-and-effect diagrams.

Chapter 6, Process Improvement, focuses on the Improvement phase of DMAIC. Principles of process improvement, including flexibility and cycle time reduction, as well as continuous versus breakthrough improvement are discussed. Useful tools for process improvement, such as process map analysis, kaizen events, mistake-proofing, and creative thinking are described. Also included are the synergistic role of lean production in Six Sigma, and the use of the Deming cycle and the seven management and planning tools for implementation planning.

Chapter 7, Process Control, deals with the final phase of DMAIC—Control—and describes the role of control systems in maintaining performance improvements. Techniques of statistical process control and developing and using control charts are the major focus of this chapter.

Chapter 8 focuses on tools and methods associated with DFSS—Design for Six Sigma. This chapter concerns developing design concepts and applying various tools for establishing functional designs that have high quality and reliability. Quality function deployment is introduced along with such tools as design for manufacturability and failure mode and effects analysis. This chapter also introduces basic concepts of reliability, how those concepts are used in design activities to predict product and system reliability performance, the application of design of experiments and Taguchi methods for robust design, design for reliability, reliability evaluation, and design verification.

In the concluding chapter, Chapter 9, Implementing Six Sigma, we discuss a variety of issues that affect an organization's ability to successfully implement and sustain Six Sigma, including effective project management, organizational culture and change management, enterprise leadership, and knowledge management.

CHAPTER FEATURES

Many chapters have unique case studies that illustrates the application of one or more key principles or techniques studied in the chapter; "Six Sigma in Practice" features that highlight applications in real organizations a set of review and

discussion questions designed to help students check their understanding of key concepts and think originally about critical issues; “Things to Do,” which provide interesting experiential or field investigation activities for students; and, as relevant, problems to apply various tools and techniques.

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- PowerPoint® presentation slides—Prepared by author Jim Evans for use in lectures.

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P A R T

I

Principles of Six Sigma

Chapter 1

The Foundations of Six Sigma:
Principles of Quality Management

Chapter 2

Principles of Six Sigma

CHAPTER

1

The Foundations of Six Sigma: Principles of Quality Management

Many years ago, quality guru Joseph Juran defined **breakthrough** as the accomplishment of any improvement that takes an organization to unprecedented levels of performance. To compete in today's world, every organization needs to improve. One illustration of this is Hyundai Motor Co. Although Hyundai dominated the Korean car market, it had a poor reputation for quality overseas and was losing money. Customers complained about doors that didn't fit properly, frames that rattled, and engines that delivered weak acceleration. When Chung Mong Koo became CEO in 1999, he visited Hyundai's plant at Ulsan. To the shock of his employees, who had rarely seen the CEO, Chung walked onto the factory floor and examined a Sonata sedan. He didn't like what he saw: loose wires, tangled hoses, bolts painted in four different colors—the kind of sloppiness you'd never see in a Japanese car. He immediately told the plant manager to paint all bolts and screws black and ordered workers not to release a car unless everything was done correctly. "You've got to get back to basics. The only way we can survive is to raise our quality to Toyota's level," he fumed.¹ The next year, U.S. sales rose by 42 percent, and within a few years, Hyundai's performance in the J.D. Power Initial Quality Study jumped remarkably. Since then, the brand has captured a significant share of the American market.

Performance improvement can include better design of goods and services, reduction of manufacturing defects and service errors, more streamlined and efficient operations, faster customer response, better employee skills—clearly the list goes on and on. Improvement takes a lot of work, but having the right methodologies and tools is important and can make the task considerably easier. It requires a structured approach, disciplined thinking, and the engagement of everyone in the organization. These elements have been the foundation for many approaches to quality and productivity improvement over the years.

This book is all about improving organizational processes using a body of knowledge known as Six Sigma. **Six Sigma** (and its derivative, **Lean Six Sigma**, which is explained in Chapter 2) is a performance improvement approach that seeks to find and eliminate causes of defects and errors, reduce cycle times and cost of operations, improve productivity, better meet customer expectations, and achieve higher asset utilization and returns on investment in manufacturing and service processes. Six Sigma focuses on outputs that are critical to customers and justifies improvements by demonstrating a clear financial return for the organization. As such, Six Sigma can be an important strategic initiative from both a market and financial perspective. It is based on a simple problem solving methodology called **DMAIC**, which stands for Define, Measure, Analyze, Improve, and Control. DMAIC incorporates a wide variety of statistical and other process improvement tools.

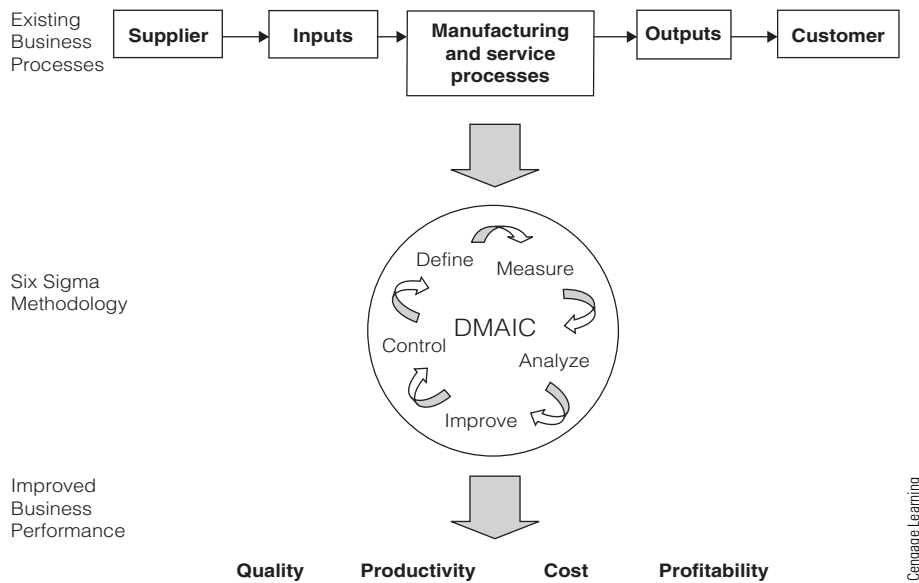
In this chapter, we discuss the principles of modern quality management, which both historically and philosophically provide the foundation for Six Sigma.

SIX SIGMA AND PERFORMANCE IMPROVEMENT

The business case for Six Sigma was eloquently stated more than a century ago. In October 1887, William Cooper Procter, grandson of the founder of Procter & Gamble, told his employees, “The first job we have is to turn out quality merchandise that consumers will buy and keep on buying. If we produce it efficiently and economically, we will earn a profit, in which you will share.” Procter’s statement addresses four key issues: *quality, productivity, cost, and profitability*. The quality of the goods and services that create customer satisfaction, productivity (the measure of efficiency defined as the amount of output achieved per unit of input), and the cost of operations all contribute to profitability. Six Sigma is focused on improving each of these four basic metrics. Figure 1.1 provides a model that suggests how Six Sigma, through the DMAIC process, can provide a bridge for performance improvement that helps realize the performance goals of improved quality, productivity, cost, and profitability.

Motorola pioneered the concept of Six Sigma, and its popularity and credibility increased after it was accepted at many other major firms, including Allied Signal (now part of Honeywell) and General Electric. The late Bill Smith, a reliability engineer at Motorola, is credited with originating the concept during the mid-1980s and selling it to Motorola’s CEO, Robert Galvin. Smith noted that system failure rates were substantially higher than predicted by final product tests, and he suggested several causes, including higher system complexity that resulted in more opportunities for failure and a fundamental flaw in traditional quality thinking. Smith concluded that a much higher level of internal quality was required and convinced Galvin of its importance.²

The term *six sigma* is based on a statistical measure that equates to 3.4 or fewer errors or defects per million opportunities. In this book we distinguish between *six sigma*—the defect- or error-based metric, and *Six Sigma*—the approach and philosophy. An ultimate “stretch” goal of all organizations that adopt a Six Sigma

FIGURE 1.1 SIX SIGMA AND PROCESS IMPROVEMENT

philosophy is to have all critical processes, regardless of functional area, at a six-sigma level of capability. As a result, Motorola set a goal in 1987 to improve product and service quality ten times by 1989, at least one hundred fold by 1991, and to achieve six-sigma capability by 1992. Their objective was to foster quality in every facet of the corporation and achieve a culture of continual improvement to assure total customer satisfaction. As Motorola noted, “There is only one ultimate goal: zero defects—in everything we do.” Today, Six Sigma is used extensively in a wide variety of manufacturing and service organizations and is an important approach in modern health care.

The core philosophy of Six Sigma is based on some key concepts:³

1. Think in terms of key organizational processes and customer requirements with a clear focus on overall strategic objectives.
2. Focus on high-level executive sponsors responsible for championing projects, supporting team activities, helping to overcome resistance to change, and obtaining resources.
3. Emphasize such quantifiable measures as *defects per million opportunities (dpmo)* that can be applied to all parts of an organization: manufacturing, service, engineering, administrative, software, and so on.
4. Ensure that appropriate metrics are identified early in the process and that they focus on business results, thereby providing incentives and accountability.
5. Provide extensive training followed by project team deployment to improve profitability, reduce non-value-added activities, and achieve cycle time reductions.

6. Create highly qualified process improvement experts who can apply improvement tools and lead teams.
7. Set stretch objectives for improvement.

These concepts provide a logical and disciplined approach to improving business performance, engaging the workforce, and meeting the goals and objectives of top management. Thus, Six Sigma, unlike many other improvement approaches such as reengineering, fits well within existing organizational structures.

THE EVOLUTION OF SIX SIGMA

Although Six Sigma only emerged as a unique discipline rather recently, the tools and approaches it uses were created over the long history of quality management, which itself has drawn on other disciplines such as industrial engineering, statistics, human resource management, and organization theory. In this section we briefly review the history of quality management leading to Six Sigma.

Ancient Origins

Quality management dates back thousands of years. Egyptian wall paintings circa 1450 B.C. show evidence of measurement and inspection.⁴ Stones for the pyramids were cut so precisely that even today it is impossible to put a knife blade between the blocks. The Egyptians' success resulted from the consistent use of well-developed methods and procedures and precise measuring devices for assuring quality.

Modern quality assurance methods actually began millennia ago in China during the Zhou Dynasty. Specific governmental departments were created and given responsibility for:

- Production, inventory, and product distribution of raw material (what we now call supply chain management)
- Production and manufacturing
- Formulating and executing quality standards
- Supervision and inspection

These departments were well organized and helped establish China's central control over production processes. The system even included an independent quality organization responsible for end-to-end oversight that reported directly to the highest level of government.

The Age of Craftsmanship

During the Middle Ages in Europe, the skilled craftsperson served as both manufacturer and inspector. "Manufacturers" who dealt directly with customers took considerable pride in workmanship. Craft guilds, consisting of masters, journeymen, and apprentices, emerged to ensure that craftspeople were adequately trained. Quality assurance was informal; every effort was made to ensure that quality was built into the final product by the people who produced it. These themes, which were lost with the advent of the Industrial Revolution, are important foundations of modern quality assurance efforts.

The Industrial Revolution

During the middle of the eighteenth century, a French gunsmith, Honoré Le Blanc, developed a system for manufacturing muskets to a standard pattern using interchangeable parts. Thomas Jefferson brought the idea to America, and in 1798, the new U.S. government awarded Eli Whitney a two-year contract to supply 10,000 muskets to its armed forces. The use of interchangeable parts necessitated careful control of quality. While a customized product built by a craftsperson can be tweaked and hammered to fit and work correctly, random matching of mating parts provides no such assurance. The parts must be produced according to a carefully designed standard. Whitney designed special machine tools and trained unskilled workers to make parts following a fixed design, which were then measured and compared to a model. He underestimated the effect of variation in production processes, however (an obstacle that continues to plague companies to this day). Because of the resulting problems, Whitney took more than 10 years to complete the project. Nonetheless, the value of the concept of interchangeable parts was recognized, and it eventually led to the Industrial Revolution, making quality assurance a critical component of the production process.

Quality Assurance

In the early 1900s, the work of Frederick W. Taylor, often called the “father of scientific management,” led to a new philosophy of production. Taylor’s philosophy was to separate the planning function from the execution function. Managers and engineers were given the task of planning; supervisors and workers took on the task of execution. This approach worked well at the turn of the century, when workers lacked the education needed for doing planning. By segmenting a job into specific work tasks and focusing on increasing efficiency, quality assurance fell into the hands of inspectors. Manufacturers were able to ship good-quality products, but at great cost. Defects were present, but were removed by inspection. Plants employed hundreds, even thousands, of inspectors. Inspection was thus the primary means of quality control during the first half of the twentieth century.

Eventually, production organizations created separate quality departments. This artificial separation of production workers from responsibility for quality assurance led to indifference to quality among both workers and their managers. Concluding that quality was the responsibility of the quality department, many upper managers turned their attention to output quantity and efficiency. Because they had delegated so much responsibility for quality to others, upper managers had little knowledge about quality, and when the quality crisis hit, they were ill-prepared to deal with it.

Ironically, one of the leaders of the second Industrial Revolution, Henry Ford, Sr., developed many of the fundamentals of what we now call “total quality practices” in the early 1900s. This piece of history was not discovered until Ford executives visited Japan in 1982 to study Japanese management practices. As the story goes, one Japanese executive referred repeatedly to “the book,” which the Ford people learned was a Japanese translation of *My Life and Work*, written by Henry Ford and Samuel Crowther in 1926 (New York: Garden City Publishing Co.). “The book” had become Japan’s industrial bible and helped Ford Motor Company realize how far it had strayed from its founding principles over the years. Quality

historians noted that Ford executives had to go to a used bookstore to find a copy when they returned to the United States.

The Bell System was the leader in the early modern history of industrial quality assurance.⁵ It created an inspection department in its Western Electric Company in the early 1900s to support the Bell operating companies. Although the Bell System achieved its noteworthy quality through massive inspection efforts, the importance of quality in providing telephone service across the nation led Bell to research and develop new approaches. In the 1920s, employees of Western Electric's inspection department were transferred to Bell Telephone Laboratories. The duties of this group included the development of new theories and methods of inspection for improving and maintaining quality. The early pioneers of quality assurance—Walter Shewhart, Harold Dodge, George Edwards, and others, including W. Edwards Deming—were members of this group. These pioneers not only coined the term *quality assurance*, they also developed many useful techniques for improving quality and solving quality problems. Thus, quality became a technical discipline of its own.

The Western Electric group, led by Walter Shewhart, ushered in the era of statistical quality control (SQC), the application of statistical methods for controlling quality. SQC goes beyond inspection to focus on identifying and eliminating the problems that cause defects. Shewhart is credited with developing control charts, which became a popular means of identifying quality problems in production processes and ensuring consistency of output. Others in the group developed many other useful statistical techniques and approaches.

During World War II, the United States military began using statistical sampling procedures and imposing stringent standards on suppliers. The War Production Board offered free training courses in the statistical methods developed by the Bell System. The impact on wartime production was minimal, but the effort developed quality specialists, who began to use and extend these tools within their organizations. Thus, statistical quality control became widely known and gradually adopted throughout manufacturing industries. Professional societies—notably the American Society for Quality Control (now called the American Society for Quality, <http://www.asq.org>)—were founded to develop, promote, and apply quality concepts.

Growth of Quality in Japan

After the war, during the late 1940s and early 1950s, the shortage of civilian goods in the United States made production a top priority. In most companies, quality remained the province of the specialist, however. Quality was not a priority of top managers, who delegated this responsibility to quality managers. Top management showed little interest in quality improvement or the prevention of defects and errors, relying instead on mass inspection.

During this time, two U.S. consultants, Dr. Joseph Juran and Dr. W. Edwards Deming, introduced statistical quality control techniques to the Japanese to aid them in their rebuilding efforts. A significant part of their educational activity was focused on upper management, rather than quality specialists alone. With the support of top managers, the Japanese integrated quality throughout their organizations and developed a culture of continuous improvement (sometimes referred to by the Japanese term *kaizen*, pronounced *ki-zen*).

Improvements in Japanese quality were slow and steady; some 20 years passed before the quality of Japanese products exceeded that of Western manufacturers. But by the 1970s, primarily because of higher quality levels, Japanese companies had penetrated many Western markets, such as computer memory chips, consumer electronics, and automobiles. For example, a *Business Week* special report on quality dated June 8, 1987, noted that the number of problems reported per 100 domestic car models in the first 60 to 90 days of ownership averaged between 162 and 180. Comparable figures for Japanese and German automobiles were 129 and 152, respectively. Consumers began to notice these quality differences and consequently, began to expect and demand high quality and reliability in goods and services at a fair price. U.S. business recognized the crisis.

The U.S. “Quality Revolution”

The decade of the 1980s was a period of remarkable change in business perceptions of quality and how it should be managed. Quality became vital to organizational survival. Xerox, for instance, discovered that its Japanese competitors were selling small copiers for what it cost Xerox to make them at the time. Xerox immediately initiated a corporate-wide quality improvement focus to meet the challenge. Xerox and its former CEO David Kearns, who led its “Leadership Through Quality” initiative, were major influences in the promotion of quality among U.S. corporations at the time. In the five years of continuous improvement culminating in the firm’s receiving the Malcolm Baldrige National Quality Award in 1989, defects per 100 machines were decreased by 78 percent; unscheduled maintenance was decreased by 40 percent; manufacturing costs dropped 20 percent; product development time decreased by 60 percent; overall product quality improved 93 percent; service response time was improved by 27 percent; and the company recaptured much of the market it had lost. The company experienced strong growth during the 1990s. However, by 2000, Xerox had lost its focus on quality as a key business driver, much of it because of shortsightedness on the part of former top management. Fortunately, new corporate leadership recognized the crisis (again) and renewed its focus and commitment to quality (see the case study at the end of this chapter).

A Westinghouse (now CBS) vice president of corporate productivity and quality summed up the situation by quoting the seventeenth century writer, Dr. Samuel Johnson: “Nothing concentrates a man’s mind so wonderfully as the prospect of being hanged in the morning.” Quality excellence became recognized as key to worldwide competitive advantage and was heavily promoted throughout industry.⁶ Most major U.S. companies instituted extensive quality improvement campaigns, directed not only at improving internal operations, but also toward satisfying external customers.

One of the most influential individuals in the quality revolution was W. Edwards Deming. In 1980, NBC televised a special program entitled “If Japan Can . . . Why Can’t We?” The widely viewed program revealed Deming’s key role in the development of Japanese quality, and his name was soon a household word among corporate executives. Although Deming had helped to transform Japanese industry three decades earlier, it was only after the television program that U.S. companies asked for his help. From 1980 until his death in 1993, his leadership and expertise helped many U.S. companies revolutionize their approach to quality.

During that period (late 1980s through the 1990s), interest in quality grew at an unprecedented rate. Companies made significant strides in improving quality. Many gaps between Japanese and U.S. quality began to narrow, and U.S. firms regained much of the ground they had lost. In 1989, Florida Power and Light was the first non-Japanese company to be awarded Japan's coveted Deming Prize for quality, followed by AT&T Power Systems five years later. Quality practices expanded into the service sector and into nonprofit organizations such as schools and hospitals. By the mid-1990s, thousands of professional books had been written, and quality-related consulting and training had blossomed into an industry. Companies began to share their knowledge and experience through formal and informal networking.

Total Quality Management

Although quality initiatives focused initially on reducing defects and errors in goods and services, organizations began to recognize that lasting improvement could not be accomplished without a more comprehensive systems perspective and use of the scientific method. This led to the notion of **total quality management**, or **TQM**, which was based on three key principles:

- focusing on customers
- continuous improvement
- employee participation and empowerment

The TQM philosophy provided a comprehensive approach to building excellence in organizations, but many top managers had difficulty implementing it. Top management often did not fully understand it, nor did they see measurable returns. Quite often, TQM was simply viewed as a collection of tools applied at low levels of the organization. TQM was not viewed strategically, and as a result, it lost favor among many business executives.

Six Sigma has many different characteristics when compared with TQM, which made it more appealing:⁸

- TQM is based largely on worker empowerment and teams; Six Sigma is owned by business leader champions.
- TQM activities generally occur within a department, process, or individual workplace; Six Sigma projects are often cross-functional and more strategic in nature.
- TQM training is generally limited to simple improvement tools and concepts; Six Sigma focuses on a more rigorous and advanced set of statistical methods and a structured problem-solving methodology, DMAIC (define, measure, analyze, improve, and control), which is discussed in Chapter 2.
- TQM is focused on improvement with little financial accountability; Six Sigma requires a verifiable return on investment and focus on the bottom line.

We should point out, however, that although the term TQM is not used much anymore, the principles are still alive in many organizations and underlie the Six Sigma philosophy. For example, in Dell's 2003 annual report, the company stated that "[we] regularly assess ourselves against a broad range of customer focused