The Certified Six Sigma Black Belt Handbook

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For my grandchildren Sarah, Emily, Dana, Josiah, Regan, Alec, and Liam.

—Donald W. Benbow

For Jenna, my granddaughter:

As my son has changed my life, so too you have changed his. Know that life is a cycle and process rife with many improvement opportunities, distractions, setbacks, and challenges. There will be forces seemingly intent on diverting your path. Stand strong in your convictions and values. Pace yourself for a long and prosperous journey, but never fail to face a challenge head-on or seize an opportunity to grow. When in doubt, seek out guidance from friends and family. You only have to ask. And don't be afraid to say, "I don't know." Do what is right for you. For, in the end, you must answer only to yourself. Today, these are only words. Someday, they will have meaning when your life is changed, too.

—T. M. Kubiak

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Preface

We decided to number chapters and sections by the same method used in the Body of Knowledge (BOK) specified for the Certified Six Sigma Black Belt examination. This made some awkward placement (the normal distribution is referred to several times before it is defined) and in some cases redundancy. We thought the ease of access for readers, who might be struggling with some particular point in the BOK, would more than balance these disadvantages.

The enclosed CD contains supplementary problems covering each chapter and a simulated exam that has problems distributed among chapters according to the scheme published in the Body of Knowledge. It is suggested that the reader study a particular chapter, repeating any calculations independently, and then do the supplementary problems for that chapter. After attaining success with all chapters, the reader may complete the simulated exam to confirm mastery of the entire Six Sigma Black Belt Body of Knowledge.

—The Authors

Acknowledgments

Thanks to Hossain Sebghati, Craig Jeffers, and Shelly Clausen of Electrolux Laundry Products at Webster City, Iowa, for working with early drafts of this book.

—Donald Benbow

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—T. M. Kubiak

Chapter I

Enterprise-wide Deployment

I.A. ENTERPRISE VIEW

I.A.1. Value of Six Sigma

A wide range of companies have found that when the Six Sigma philosophy is fully embraced, the enterprise thrives. What is this Six Sigma philosophy? Several definitions have been proposed. The threads common to these definitions are:

- Use of teams that are assigned well-defined projects that have direct impact on the organization's bottom line.
- Training in "statistical thinking" at all levels and providing key people with extensive training in advanced statistics and project management. These key people are designated "black belts."
- Emphasis on the DMAIC approach to problem solving: define, measure, analyze, improve, and control.
- A management environment that supports these initiatives as a business strategy.

The literature is replete with examples of projects that have returned high dollar amounts to the organizations involved. A requirement often placed on black belts is that they manage four projects per year for a total of $500,000 to $5,000,000 in contributions to the company's bottom line.

Opinions on the definition of Six Sigma can differ:

- Philosophy—The philosophical perspective views all work as processes that can be defined, measured, analyzed, improved, and controlled (DMAIC). Processes require inputs and produce outputs. If you control the inputs, you will control the outputs. This is generally expressed as the $y = f(x)$ concept.
- Set of Tools—Six Sigma as a set of tools includes all the qualitative and quantitative techniques used by the Six Sigma expert to drive process improvement. A few such tools include statistical process control (SPC), control charts, failure mode

and effects analysis, and process mapping. There is probably little agreement among Six Sigma professionals as to what constitutes the tool set.

- Methodology—This view of Six Sigma recognizes the underlying and rigorous approach known as DMAIC. DMAIC defines the steps a Six Sigma practitioner is expected to follow, starting with identifying the problem and ending with the implementation of long-lasting solutions. While DMAIC is not the only Six Sigma methodology in use, it is certainly the most widely adopted and recognized.
- Metrics—In simple terms, Six Sigma quality performance means 3.4 defects per million opportunities (accounting for a 1.5-sigma shift in the mean).

Six Sigma is a fact-based, data-driven philosophy of improvement that values defect prevention over defect detection. It drives customer satisfaction and bottom-line results by reducing variation and waste, thereby promoting a competitive advantage. It applies anywhere variation and waste exist, and every employee should be involved.

At this point, Six Sigma purists will be quick to say, "You're not just talking about Six Sigma; you're talking about lean too." Today, the demarcation between Six Sigma and lean has blurred. With greater frequency, we are hearing about terms such as "sigma-lean," because process improvement requires aspects of both approaches to attain positive results.

Six Sigma focuses on reducing process variation and enhancing process control, while lean—also known as lean manufacturing—drives out waste (non-value-added) and promotes work standardization and flow. Six Sigma practitioners should be well versed in both. More details of what is sometimes referred to as lean thinking are given in Section C of Chapter VIII and in Chapter IX.

I.A.2. Business Systems and Processes

Processes

A process is a series of steps designed to produce products and / or services. A process is often diagrammed with a flowchart depicting inputs, a path that material or information follows and outputs. An example of a process flowchart is shown in Figure I.1. Understanding and improving processes is a key part of every Six Sigma project.

The basic strategy of Six Sigma is contained in the acronym DMAIC, which stands for define, measure, analyze, improve, and control. These steps constitute the cycle used by Six Sigma practitioners to manage problem-solving projects. The individual parts of the DMAIC cycle are explained in Chapters IV–VIII.

Business Systems

A business system is designed to implement a process or, more commonly, a set of processes. Business systems make certain that process inputs are in the right place at the right time so that each step of the process has the resources it needs. Perhaps most importantly, a business system must have as its goal the continual improvement of its processes, products, and services. To this end the business system is responsible for collecting and analyzing data from the process and other sources that will help in the continual incremental improvement of process outputs. Figure 1.2 illustrates relationships between systems, processes, subprocesses, and steps.

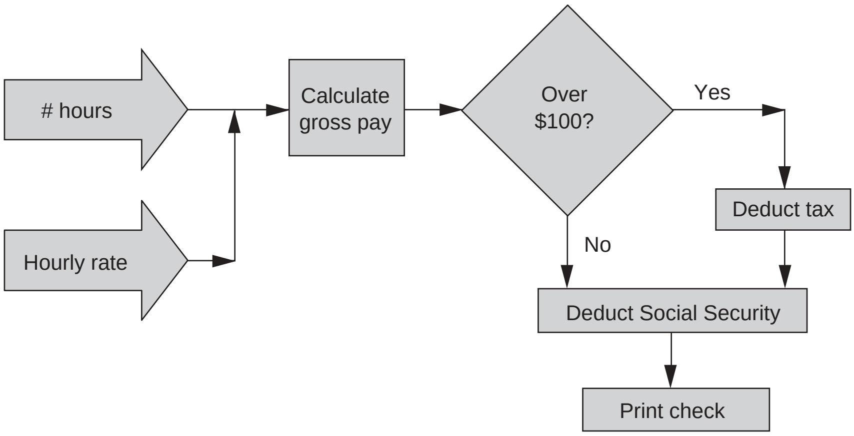

Figure I.1 Example of a process flowchart.

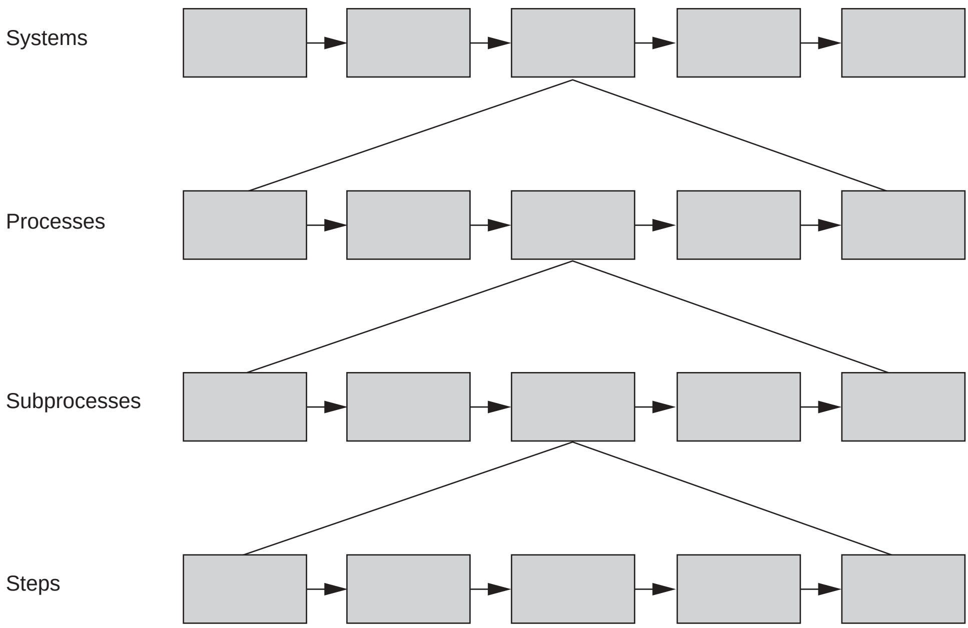

Figure I.2 Relationship between systems, processes, subprocesses and steps. Each part of a system can be broken into a series of processes, each of which may have subprocesses. The subprocesses may be further broken into steps.

I.A.3. Process Inputs, Outputs, and Feedback

Figure 1.3 illustrates an application of a feedback loop to help in process control. It is often useful to expand on a process flowchart with more elaborate diagrams. An example is shown in Section V.A. Various versions of these diagrams are called process maps, value stream maps, and so on. Their common feature is an emphasis on inputs and outputs for each process step, the output from one step being the input to the next step. Each step acts as the customer of the previous step and supplier to the next step. The value to the parent enterprise system lies in the quality of these inputs and outputs and the efficiency with which they are managed. There are two ways to look at the method by which efficient use of inputs / resources is implemented to produce quality outputs:

- Some would state that a function of process management is the collection and analysis of data about inputs and outputs, using the information as feedback to the process for adjustment and improvement.
- Another way of thinking about this is that the process should be designed so that data collection, analysis and feedback for adjustment and improvement are a part of the process itself.

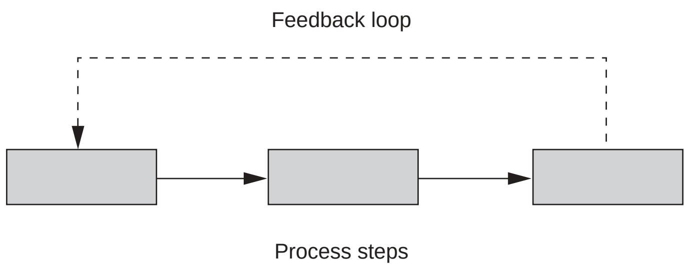

Figure I.3 A feedback loop.

Either approach shows the importance of the design of an appropriate data collection, analysis, and feedback system. This begins with decisions about the points at which data should be collected. The next decisions encompass the measurement systems to be used. Details of measurement system analysis are discussed in Section V.E. The third set of decisions entails the analysis of the data. Data analysis is covered in parts of Chapters V–VIII. The fourth set of decisions regards the use of the information gleaned from the data.

- Sometimes the information is used as real-time feedback to the process, triggering adjustment of inputs. A typical example would involve the use of a control chart. Data are collected and recorded on the chart. The charting process acts as the data analysis tool. The proper use of the chart sometimes suggests that a process input be adjusted.
- Another use for the information would be in the formation of plans for process improvement. If a stable process is found to be incapable, for instance, designed experiments may be required.

Any enterprise system must perform process improvement as part of its day-to-day operation. Only in this way can the enterprise prosper.

Figure 1.4 shows the categories of inputs to a process step. It is helpful to list inputs in the various categories and then classify each input as indicated.

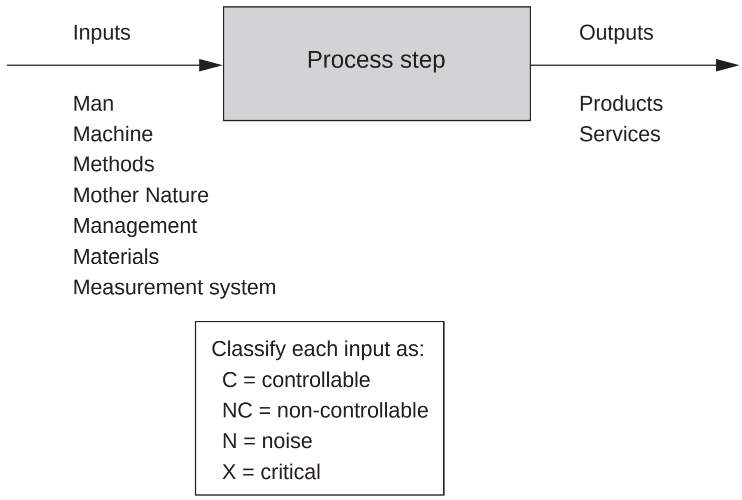

Figure I.4 Categories of inputs.

I.B. LEADERSHIP

I.B.1. Enterprise Leadership

The definition and role of leadership have undergone major shifts in recent years. The leadership model that is most effective in the deployment of Six Sigma envisions the leader as a problem solver. The leader's job is to implement systems that identify and solve problems that impede the effectiveness of the processes. This requires two steps:

- Allocate resources to support team-based problem identification and solution.
- Allocate resources to install corrections and ensure that the problems will not recur.

This concept of leadership implies a good understanding of team dynamics and Six Sigma problem-solving techniques. Deployment of a culture-changing initiative such as the adoption of Six Sigma rarely succeeds without engaged, visible, and active senior-level management involvement. Initiatives starting in the rank-and-file seldom gain the critical mass necessary to sustain and fuel their own existence.

I.B.2. Six Sigma Roles and Responsibilities

Enterprises with successful Six Sigma programs have found it useful to delineate roles and responsibilities for various people involved in project activity. Although titles vary somewhat from company to company, the following list is the most common. Descriptions labeled **QP** are from a glossary assembled by *Quality Progress* and accessible at www.SixSigmaForum.com.

Black Belts (sometimes called agents or program managers)

Black belts work full time on Six Sigma projects. These projects are usually prioritized based on their potential financial impact on the enterprise. Individuals designated as black belts must be thoroughly trained in statistical methods and be proficient at working with teams to implement project success. Breyfogle[1] suggests that the number of black belts should equal about 1% of the number of employees in the organization.

QP Black Belt (BB): Full-time team leader responsible for implementing process improvement projects—define, measure, analyze, improve, and control (DMAIC) or define, measure, analyze, design, and verify (DMADV)—within the business to drive up customer satisfaction levels and business productivity.

Master Black Belts

Master black belts have advanced knowledge in statistics and other fields and provide technical support to the black belts.

QP Master Black Belt (MBB): Six Sigma or quality experts responsible for strategic implementations within the business. The master black belt is qualified to teach other Six Sigma facilitators the methodologies, tools, and applications in all functions and levels of the company and is a resource for utilizing statistical process control within processes.

Green Belts

A green belt works under the direction of a black belt, providing assistance with all phases of project operation. Green belts typically are less adept at statistics and other problem-solving techniques.

QP Green Belt (GB): A business team leader responsible for managing projects and implementing improvement in his or her organization. An employee of an organization who has been trained on the improvement methodology of Six Sigma and will lead a process improvement or quality improvement team as part of his or her full-time job.

Champions

A champion is typically a top-level manager who is familiar with the benefits of Six Sigma strategies and provides support for the program.

QP Champion: A business leader or senior manager who ensures that resources are available for training and projects and who is involved in project tollgate reviews; also an executive who supports and addresses Six Sigma organizational issues.

Executive

The most successful implementations of Six Sigma have had strong support from either the company president, the CEO, or another key executive.

Process Owners

Process owners should be sufficiently high in the organization to make decisions regarding process changes. It is only natural that managers with responsibility for a particular process frequently have a vested interest in keeping things as they were. They should be involved with any discussion of change. In most cases they are willing to support changes but need to see evidence that the proposal is for the long-term good of the enterprise. A team member with a "show me" attitude can make a very positive contribution to the team. Process owners should be provided with opportunities for training at least to the green belt level.

QP Process Owner: The person who coordinates the various functions and work activities at all levels of a process, has the authority or ability to make changes in the process as required, and manages the entire process cycle to ensure performance effectiveness.

I.C. ORGANIZATIONAL GOALS AND OBJECTIVES

I.C.1. Linking Projects to Organizational Goals

Organizational goals must be consistent with the long-term strategies of the enterprise. One technique for developing such strategies is called Hoshin planning. This is a planning process in which a company develops up to four vision statements that indicate where the company should be in the next five years. Company goals and work plans are developed based on the vision statements. Periodic audits are then conducted to monitor progress.

Once Six Sigma projects have had some successes, there will usually be more project ideas than it is possible to undertake at one time. Some sort of project proposal format may be needed, along with an associated process for project selection. It is common to require that project proposals include precise statements of the problem definition and some preliminary measures of the seriousness of the problem, including its impact on the goals of the enterprise.

A project selection group, including master black belts, black belts, organizational champions, and key executive supporters, establish a set of criteria for project selection and team assignments. In some companies the project selection group assigns some projects to Six Sigma teams and other projects to teams using other methodologies. For example, problems involving extensive data analysis and improvements using designed experiments would likely be assigned to a Six Sigma team, while a process improvement not involving these techniques might be assigned to a "lean manufacturing" team. New product design should follow the DFSS guidelines as detailed in Chapter X.

The project selection criteria always have as key elements the furthering of organizational goals. One key to gauging both the performance and health of an organization and its processes lies with its selection and use of metrics. These are usually converted to financial terms such as return on investment, cost reduction, increases in sales, and/or profit. Other things being approximately equal, the projects with greatest contributions to the bottom line receive the highest priority. More details on project metrics are covered in section II.A.4.

I.C.2. Risk Analysis

The formula for expected profit is EP = Σ Profit × Probability.

Example: A gambler is considering whether to bet $1.00 on red at a roulette table. If the ball falls into a red cell, the gambler will receive a $1.00 profit. Otherwise the gambler will lose the $1.00 bet. The wheel has 38 cells, 18 being red.

Analysis: Assuming a fair wheel, the probability of winning is $18 / 38 \approx 0.474$ and the probability of losing is $20 / 38 \approx 0.526$. In table form, it looks like this:

Outcome	Profit	Probability	Profit × Probability
Win	$1	.474	$.474
Lose	–$1	.526	–$.526
Expected profit = –$0.052			

In this case the gambler can expect to lose an average of about a nickel (–$ 0.052) for each $1.00 bet. Risk analysis for real-life problems tends to be less precise primarily because the probabilities are usually not known and must be estimated.

Example: A proposed Six Sigma project is aimed at improving quality enough to attract one or two new customers. The project will cost $3 M. Previous experience indicates that the probability of getting customer A only is between 60% and 70% and the probability of getting customer B only is between 10% and 20%. The probability of getting both A and B is between 5% and 10%.

One way to analyze this problem is to make two tables, one for the worst case and the other for the best case, as indicated in Table 1.1.

Table I.1 Risk analysis table.

	Worst Case			Best Case		
Outcome	Profit	Probability	Profit × Probability	Profit	Probability	Profit × Probability
A only	$2 M	.60	$1.2 M	$2 M	.70	$1.4 M
B only	$2 M	.10	$0.2 M	$2 M	.20	$0.4 M
A & B	$7 M	.05	$0.35 M	$7 M	.10	$0.7 M
None	–$3 M	.25	–$0.75 M	–$3 M	0	$0 M
Expected Profit = $1 M				Expected Profit = $2.5 M		

Assuming that the data are correct, the project will improve profit of the enterprise by between $1 M and $2.5 M.

When estimating the values for these tables, the project team should list the strengths, weaknesses, opportunities, and threats (SWOT) that the proposal implies. A thorough study of this list will help provide the best estimates (see Figure 1.5).

A "system" may be thought of as the set of processes that make up an enterprise. When improvements are proposed, it is important to take a systems approach. This

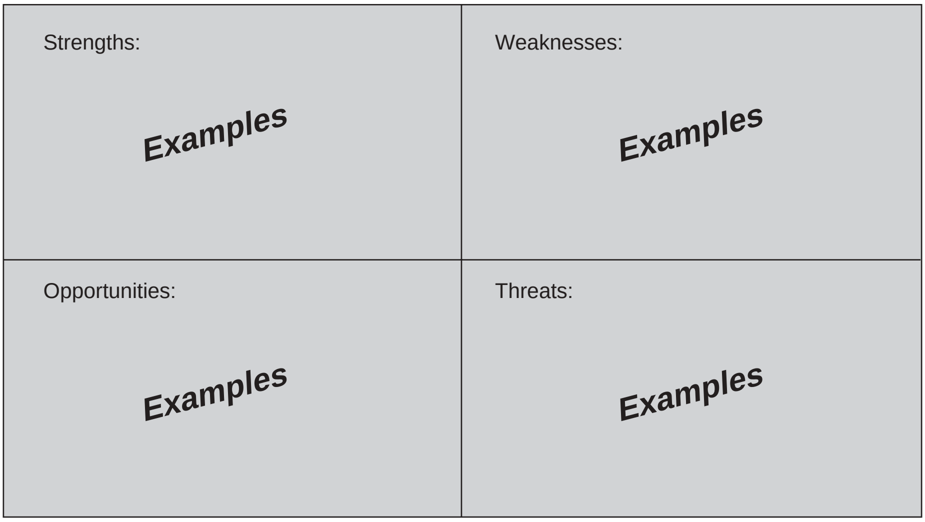

Figure I.5 A format for SWOT analysis.

means that consideration should be given to the effect the proposed changes will have on other processes within the system and therefore on the enterprise as a whole. Operating a system at less than its best mode is called suboptimization. Changes in a system may optimize individual process but suboptimize the system as a whole.

Examples:

- The resources invested in improving process A might be more profitably invested in process B.
- The improvement of throughput rate for a process far beyond the ability of the subsequent process to handle.
- A distribution center loads its trucks in a manner that minimizes its work. However, this method requires the receiving organization to expend more time, energy, resources, and dollars unloading the truck. Perhaps a different loading style/arrangement may be more expensive to the distribution center but would result in significant cost reduction for the entire system.

I.C.3. Closed-loop Assessment/Knowledge Management

As projects are completed, black belt and master black belts should produce a thorough formal evaluation of the project from initial proposal until completion. Particular attention should be given to the following:

- Were the assumptions valid?
- How accurate were the SWOT projections?
- Were the objectives achieved?

- What unforeseen difficulties arose?
- What new opportunities arose?
- What lessons were learned that may apply to other projects?

I.D. HISTORY OF ORGANIZATIONAL IMPROVEMENT AND FOUNDATIONS OF SIX SIGMA

Most of the techniques found in the Six Sigma toolbox have been available for some time, thanks to the groundbreaking work of the following professionals in the quality sciences.

Walter Shewhart worked at the Hawthorne plant of Western Electric, where he developed and used control charts. He is sometimes referred to as the father of statistical quality control (SQC) because he brought together the disciplines of statistics, engineering, and economics. He described the basic principles of this new discipline in his book *Economic Control of Quality of Manufactured Product*. He was the first Honorary Member of the American Society for Quality (ASQ).

W. Edwards Deming emphasized the need for changes in management structure and attitudes. He developed a list of "Fourteen Points." As stated in his book *Out of the Crisis*,[2] the 14 points are:

1. Create constancy of purpose for improvement of product and service.
2. Adopt a new philosophy.
3. Cease dependence on inspection to achieve quality.
4. End the practice of awarding business on the basis of price tag alone. Instead, minimize total cost by working with a single supplier.
5. Improve constantly and forever every process for planning, production, and service.
6. Institute training on the job.
7. Adopt and institute leadership.
8. Drive out fear.
9. Break down barriers between staff areas.
10. Eliminate slogans, exhortations, and targets for the workforce.
11. Eliminate numerical quotas for the workforce and numerical goals for management.
12. Remove barriers that rob people of pride of workmanship. Eliminate the annual rating or merit system.
13. Institute a vigorous program of education and self-improvement for everyone.
14. Put everybody in the company to work to accomplish the transformation.

Joseph M. Juran has pursued a varied career in management since 1924 as an engineer, executive, government administrator, university professor, labor arbitrator, corporate director, and consultant. He developed the Juran trilogy, three managerial processes for use in managing for quality: quality planning, quality control, and quality improvement. Juran wrote hundreds of papers and 12 books, including *Juran's Quality Control Handbook*, *Quality Planning and Analysis* (with F. M. Gryna), and *Juran on Leadership for Quality*. His approach to quality improvement includes the following points:

- Create awareness of the need and opportunity for improvement.
- Mandate quality improvement; make it a part of every job description.
  - Create the infrastructure: Establish a quality council; select projects for improvement; appoint teams; provide facilitators.
  - Provide training in how to improve quality.
  - Review progress regularly.
  - Give recognition to the winning teams.
  - Propagandize the results.
  - Revise the reward system to enforce the rate of improvement.
  - Maintain momentum by enlarging the business plan to include goals for quality improvement.

Deming and Juran worked in both the United States and Japan to help businesses understand the importance of continuous process improvement.

Philip B. Crosby wrote many books, including *Quality Is Free*, *Quality Without Tears*, *Let's Talk Quality*, and *Leading: The Art of Becoming an Executive*. Crosby, who originated the zero defects concept, was an ASQ Honorary Member and past president. Crosby's 14 steps to quality improvement are listed here, as noted in the *Certified Quality Manager Handbook*:[3]

1. Make it clear that management is committed to quality.
2. Form quality improvement teams with representatives from each department.
3. Determine how to measure where current and potential quality problems lie.
4. Evaluate the cost of quality and explain its use as a management tool.
5. Raise the quality awareness and personal concern of all employees.
6. Take formal actions to correct problems identified through previous steps.
7. Establish a committee for the zero defects program.
8. Train all employees to actively carry out their part of the quality improvement program.
9. Hold a "zero defects day" to let all employees realize that there has been a change.
10. Encourage individuals to establish improvement goals for themselves and their groups.
11. Encourage employees to communicate to management the obstacles they face in attaining their improvement goals.

Table I.2 Some approaches to quality over the years.

Quality Approach	Approximate Time Frame	Short description
Quality Circles	1979–1981	Quality improvement or self-improvement study groups composed of a small number of employees (10 or fewer) and their supervisor. Quality circles originated in Japan, where they are called "quality control circles."
Statistical Process Control (SPC)	Mid-1980s	The application of statistical techniques to control a process. Also called "statistical quality control."
ISO 9000	1987–present	A set of international standards on quality management and quality assurance developed to help companies effectively document the quality system elements to be implemented to maintain an efficient quality system. The standards, initially published in 1987, are not specific to any particular industry, product, or service. The standards were developed by the International Organization for Standardization (ISO), a specialized international agency for standardization composed of the national standards bodies of 91 countries. The standards underwent major revision in 2000 and now include ISO 9000:2000 (definitions), ISO 9001:2000 (requirements), and ISO 9004:2000 (continuous improvement).
Reengineering	1996–1997	A breakthrough approach involving the restructuring of an entire organization and its processes.
Benchmarking	1988–1996	An improvement process in which a company measures its performance against that of best-in-class companies, determines how those companies achieved their performance levels, and uses the information to improve its own performance. The subjects that can be benchmarked include strategies, operations, processes, and procedures.
Balanced Scorecard	1990s–present	A management concept that helps managers at all levels monitor their results in their key areas.
Baldrige Award Criteria	1987–present	An award established by the U.S. Congress in 1987 to raise awareness of quality management and recognize U.S. companies that have implemented successful quality management systems. Two awards may be given annually in each of five categories: manufacturing company, service company, small business, education, and health care. The award is named after the late Secretary of Commerce Malcolm Baldrige, a proponent of quality management. The U.S. Commerce Department's National Institute of Standards and Technology manages the award, and ASQ administers it.
Six Sigma	1995–present	As described in Section I.A.
Lean Manufacturing	2000–present	As described in Chapter IX.

12. Recognize and appreciate those who participate.
13. Establish quality councils to communicate on a regular basis.
14. Do it all over again to emphasize that the quality improvement program never ends.

Armand Feigenbaum originated the concept of total quality control in his book *Total Quality Control*, published in 1951. The book has been translated into many languages, including Japanese, Chinese, French, and Spanish. Feigenbaum is an ASQ Honorary Member and served as ASQ president for two consecutive terms. He lists three steps to quality:

1. Quality leadership
2. Modern quality technology
3. Organizational commitment

Kaoru Ishakawa developed the cause-and-effect diagram. He worked with Deming through the Union of Japanese Scientists and Engineers. The *Certified Quality Manager Handbook*[3] summarizes Ishakawa's philosophy with the following points:

- Quality first—not short-term profit first.
- Consumer orientation—not producer orientation. Think from the standpoint of the other party.
- The next process is your customer—breaking down the barrier of sectionalism.
- Using facts and data to make presentations—utilization of statistical methods.
- Respect for humanity as a management philosophy—full participatory management.
- Cross-function management.

Genichi Taguchi taught that any departure from the nominal or target value for a characteristic represents a loss to society. He also popularized the use of fractional factorial designed experiments and stressed the concept of robustness.

Toyota Motor Company provided leadership in lean manufacturing systems.

Various approaches to quality have been in vogue over the years, as shown in Table I.2.

ENDNOTES

1. Breyfogle, F. W. *Implementing Six Sigma.* New York: John Wiley & Sons, 1999.
2. Deming, W. Edwards. *Out of the Crisis.* Cambridge, MA: MIT Press, 1982, 1986.
3. *Certified Quality Management Handbook,* Second Edition. Milwaukee, WI: ASQ Quality Press, 1999.

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