THE ASQ CERTIFIED SIX SIGMA GREEN BELT HANDBOOK

THIRD EDITION

RODERICK A. MUNRO, GOVIND RAMU, and DANIEL J. ZRYMIAK, Editors

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In remembrance of

DEBORAH L. HOPEN

1953-2020

The authors wish to dedicate this edition of *The ASQ Certified Six Sigma Green Belt Handbook* to the memory of Deborah L. Hopen. After her untimely passing, some came to call her the "First Lady of Quality." Deb was passionate about all aspects of quality and devoted herself to her passions with energy, warmth, and generosity. She asserted herself to establish her role as a leader and promoter, taking ASQ to peak levels of vitality and relevance. She contributed greatly to the methodology of Six Sigma as well as the "soft" quality skills to the more appropriate term of "support" quality skills.

Although Deb preferred to remain out of the limelight, she nevertheless received accolades. Among the honors and awards presented were:

- ASQ Fellow and ASQ Distinguished Service Medal
- American Productivity and Quality Center's C. Jackson Grayson Quality Pioneer Medal
- IAQ Founders Medal
- IAQ Agnes Žaludová Woman of Quality
- Asia-Pacific Quality Organization Miflora M. Gatchalian Medal for Women in Quality Leadership
- ASQ Quality Management Division Roger Berger Spirit Award
- Frank M. Gryna Award for Excellence in a Written Article on Quality Management
- Simon Collier Quality Leadership Award

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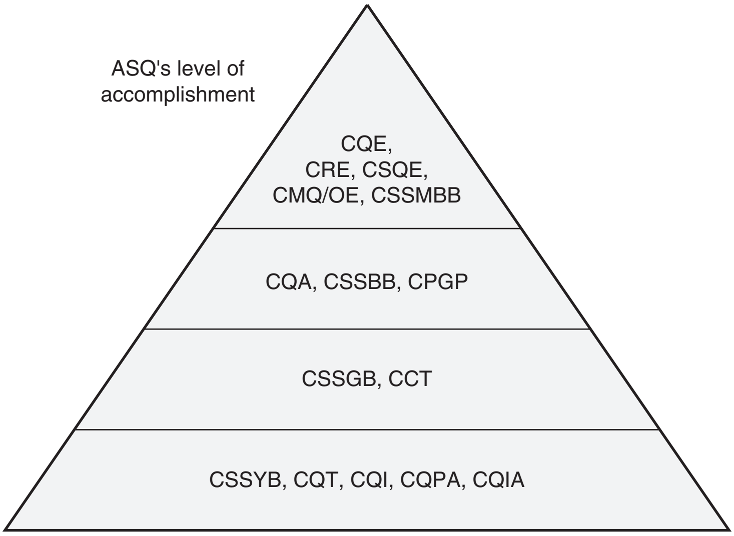
Preface to *The ASQ Certified Six Sigma Green Belt Handbook*, Third Edition

Welcome to *The ASQ Certified Six Sigma Green Belt Handbook*, Third Edition. This reference manual is designed to help those interested in passing the American Society for Quality's (ASQ) certification exam for Six Sigma Green Belts and others who want a handy reference to the appropriate materials needed to conduct successful Green Belt projects. This book is not intended to be a beginner's Six Sigma Green Belt book, but a reference handbook on running projects for those who are already knowledgeable about process improvement and variation reduction.

The primary layout of the handbook follows the American Society for Quality Body of Knowledge (BoK) for the Certified Six Sigma Green Belt (CSSGB) updated in 2022. The authors were involved with the first edition handbook and have utilized previous edition user comments, numerous Six Sigma practitioners, and their own personal knowledge gained through helping others prepare for exams to bring together a handbook that we hope will be very beneficial to anyone seeking to pass the ASQ or other Green Belt exams. In addition to the primary text, we have added two new appendices and an expanded acronym list.

WHERE ARE YOU IN YOUR CAREER?

As your professional career develops, you may wish to choose to use the tools you have learned in advancing your own career. Some have called this *career AQP*. Please visit www.asq.org to see how ASQ conducts exams to be able to advance your career. An overview of the level of accomplishment for each certification is on the next page.



CHANGES TO THE BoK AND THIS HANDBOOK

A detailed cross-matrix of the updated BoK and the previous version can be found in the appendices.

Some of the highlighted sections include: The section on tools used in Six Sigma has been moved to Chapter 7 to align with the new BoK. Several new portions have been added to the third edition to align with the new BoK.

Other major changes to the 2022 CSSGB BoK can be seen in the table below.

Content new to 2022 CSSGB BoK

BoK area	Topic	Subtopic		Description	Bloom's Taxonomy
V	B			Implementation planning	Apply
VI	B	2		Document control	Understand
VI	B	3		Training plans	Apply
VI	B	4		Audits	Remember
VI	B	5		Plan-do-check-act (PDCA)	Apply

You will also find additional content in previously existing sections of the BoK. This includes:

- SMART goals,
- Key process indicators (KPIs),
- Takt time,
- Just-in-time processes,
- Spaghetti diagrams,
- The Kano model,
- Risk management,
- Business continuity planning,
- SWOT analysis,
- RACI charts,
- Data collection plans and quality checks,
- Gap analysis,
- 5 Whys analysis,
- Fault tree analysis,
- And maintaining quality improvements.

Acknowledgments

As in any work of substance, there are a lot of people involved. The authors would like to also thank all these people for their time and support. The reviewers for this third edition worked hard with us to ensure that we covered the ASQ CSSGB BoK well. We also had many individuals assist this ongoing project by helping to develop practice exam questions for a separate book: *The ASQ CSSGB Study Guide*.

We have asked in the past, and continue to, for comments from you, our customers. If you have any comments about this handbook, we welcome to hear from you at books@asq.org.

—Roderick Munro, Govind Ramu, and Daniel Zrymiak

I would like to thank my coauthors Dan and Govind for their ongoing dedication as we strive to continually improve this handbook and help those who are striving to achieve the CSSGB level. I would also like to thank the Quality Press team and ASQE Staff for directions and guidance as we transition our organization in our new structure.

—Roderick Munro

I thank my parents Vasantha and Ramu for instilling in me passion for learning and knowledge sharing, and my wife Anitha and my children Vibha and Vivek for their encouragement, unconditional love, and support.

I want to acknowledge several quality professionals from ASQ and other professional organizations who have provided continual inspiration and guidance in writing and improving this book. Thanks to my fellow authors Rod and Dan for their friendship and support.

—Govind Ramu

I would like to acknowledge my wife Susan, my children Ryan and Brooke, and my extended family members for their personal encouragement. The ongoing and continuous support of my present and past employers and clients, my professional mentors throughout my career, and my peers and partners within the Quality community is most appreciated. Collaborations with prominent and prolific authors and experts like Govind, Rod, and Elizabeth have inspired my efforts and have been among the highlights of my service within the Quality profession.

I must also express gratitude to our community of Six Sigma and Lean Green Belt practitioners who bring these concepts to life within their workplaces and communities. Our Society is stronger through our mutual advocacy and active demonstration of these principles and practices.

—Daniel Zrymiak

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The authors would like to acknowledge the following CSSGB Handbook users who provided inputs and feedback on the errors from the first edition. We have made best effort to include everyone who provided inputs.

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THIRD EDITION ACKNOWLEDGMENTS

The authors would like to thank N. Gomez for a thoughtful detailed review of the section edition handbook that has been used to enhance the third edition. Thanks also to Jim Bossert for the time spent to review the entire manuscript.

Part I

Overview: Six Sigma and the Organization

Chapter 1	Six Sigma and Organizational Goals
Chapter 2	Lean Principles in the Organization
Chapter 3	Design for Six Sigma (DFSS) Methodologies

Each section of this book parallels a section of the ASQ Body of Knowledge (BoK) for the Certified Six Sigma Green Belt exam.

Table 1.0 CSSGB BoK section item allocation.

BoK Section	2014 BoK	2022 BoK	Difference
I. Overview: Six Sigma and the Organization	13	11	-2
II. Define Phase	23	20	-3
III. Measure Phase	23	20	-3
IV. Analyze Phase	15	18	+3
V. Improve Phase	15	16	+1
VI. Control Phase	11	15	+4

Chapter 1

Six Sigma and Organizational Goals

VALUE OF SIX SIGMA

> Recognize why organizations use six sigma, how they apply its philosophy and goals, and the evolution of six sigma from quality leaders such as Juran, Deming, Shewhart, Ishikawa, and others. (Understand)
>
> **Body of Knowledge I.A.1**

Every organization, even not-for-profits, must have a source of income in some form or another to stay in business. If an organization spends more than it takes in over time, then it will be out of business. Thus, the challenge for every organization is to become profitable at whatever it does (even if this involves soliciting contributions) so that it can continue to do what it does. Managers, employees, suppliers, process owners, stakeholders, and customers (internal or external) all have their wants and needs that the business must satisfy in an efficient manner so profit can be achieved. Thus, the first formula that every Six Sigma Green Belt must learn is the calculation for $ (we sometimes call this S-double bar, and it can be tied to the cost of quality or other financial calculations found in your organization). Without a focus on the financials and the impact that this key performance indicator has on this the bottom line, management will drift off to other random issues that will draw their attention.

Why Use Six Sigma versus Other Methodologies?

After Motorola started promoting their Six Sigma methodology in the late 1980s, there have been many skeptical of its true value. Even Jack Welch of General Electric (GE) initially dismissed the idea of Six Sigma as a passing fad in the early 1990s. However, once GE had a successful launch in one of its divisions, Six Sigma quickly became a driving force in the mid to late 1990s that started spreading across various industries. The Six Sigma buzz, fad, or whatever name it was called, started proving that it was something different, something more than the numerous other business fads that had preceded it.

The real power of Six Sigma is the use of many parts or elements of other methods that have been proven to work, in tandem with managerial focus, to create an organizational network of activities that support the efforts to continually improve on all aspects of the organization, in conjunction with standard accounting practices that demonstrate the impact of continual improvement and variation reduction on the organization's bottom line.

Six Sigma should be a large collection of tools that the organization can bring to bear as appropriate on identified issues to achieve continual improvement across the entire organization. Learning to use these various tools effectively takes time and practice and leads to the distinction of what are called *levels of competence*, or *belts*. Typical titles include White, Yellow, Green, Black, and Master Black Belt (some organizations use fewer or more belts depending on their organizational structure or needs).

How Six Sigma Philosophy and Goals Should Be Applied

With the various successes, there have been even more failures of organizations attempting to implement a Six Sigma methodology. The reasons are many; however, the most common failure is management's lack of commitment to real process improvement. Another leading reason for lack of good payback results is training too many Black Belts in the initial stages of the process, before the organization knows how to deploy the process successfully in the organization or to give those new to the use of process improvement tools time to effectively deploy these applications.

Since many managers often look for the magic bullet, they tend to hire outside consultants to come into the organization and start training Black Belts, who then are expected to conduct projects to save large amounts of cash to the bottom line. The initial waves did typically save a lot of money; however, once the consultants left, there were few internal people who understood the tools at high enough levels to encourage the use of the Six Sigma methodology. Eager to see a return on investment for all the training being done, the consultants are only engaged for short periods, and the managers then expect their internal people to move the process forward.

The truth about any process improvement effort is that it typically takes a person a full two years or more to learn how the tools work and to understand their applications. One experiment conducted in Michigan under a Robert Woods Johnson Grant involved improving performance in practice (doctor's office). Groups in several states had started this process by engaging nurses in those states and teaching them process improvement tools. They did show some success in each program tried. However, the group in Michigan engaged the Automotive Industry Action Group (AIAG), and the top doctors of the U.S. automotive industry got involved by directing that quality engineering and process engineers be used instead of nurses to go into the selected doctors' offices around the state. The AIAG taught the engineers the basics of working in a doctor's office and sent them out to work on processes. Nurses were not excluded, but worked with the quality engineers, who knew how to use the tools.

The results were outstanding and leapfrogged the other seven states involved in the study. One of the head doctors was Joseph Fortuna, MD, who subsequently became the chair of the ASQ Healthcare Division and promoted the use of process engineers in the healthcare field.

What was learned and recognized is that a good understanding of the basic tools should be the first step in setting up a Six Sigma process. This is why some companies today choose to start their process improvement journey by training Green Belts first. Management also needs to learn how these tools work so that they can direct and ask pertinent questions of those running the projects in the organization. The other key is to engage the accounting department very early in the deployment, as they must be able to substantiate the cost savings being claimed or achieved if the Six Sigma methodology is truly going to show the bottom-line (sometime jokingly called the S-double bar) savings and return on investment in the process. A good video demonstrating this was actually created back in the mid-1950s, called *Right First Time* (or sometimes *Right the First Time*).

Thus, management should use the tool of *advanced quality planning* (AQP) to prepare for a Six Sigma deployment to increase the likelihood of success within their organization. In using AQP, managers need to start learning the tools themselves, start engaging the organization using data-driven decision making, and start training Green Belts to work on small projects that can grow in time into larger projects where Black Belts can be trained and utilized more effectively. As the process gains steam within the organization, S-double bar is used (one tool here could be cost of quality) as a focal point for the organization in moving projects through the system to continually improve the processes for customer satisfaction.

The Lead-Up to the Six Sigma Methodology

Over the centuries, managers have tried to find ways to keep their organization in business (sometimes called the *magic bullet*). Many different techniques have been employed over the years to keep customers coming back time and time again. Unfortunately for many organizations, customer wants and needs change over time, leaving the organization with the challenge of finding new and better ways of satisfying those needs and wants. The concept of setting standards of work goes back many centuries and was the foundation of the guilds and crafts trades that developed over the years. During the mid-1800s to early 1900s, separation of work was developed to speed up the process of development and production. Innovators like Frederick W. Taylor and Henry Ford developed ideas and techniques that are still with us today. On the quality side of the production calculation, many techniques have been tried, starting with control charts in the 1920s–1930s by Walter Shewhart.

In the early part of the last century, given the methods of doing business, the *quality control/quality assurance* (QC/QA) specialist was created to ensure that standards were established and maintained so that customers would be satisfied. In many organizations, however, this also created a separation of tasks, and many people in organizations came to think of the responsibility for satisfying customers as only in the hands of the people in the QC/QA groups/departments instead of in the hands of the people who actually did the work of making the product or providing the service. This was especially true in the United States during the decades of the 1950s, 1960s, and 1970s as managers looked for better ways to try to manage all the resources of the organization. Many organizations still struggle with customer satisfaction!

In the mid-1920s a young engineer named Walter Shewhart devised a technique of using graphs to monitor a process to identify whether that process was acting in a predicable manner or if what he termed *special causes* were affecting the process. These charts became known as *quality control charts* (the *p*-chart was the first to be used); however, today we sometimes call them *process behavior charts*, as we want to look at what the process is doing in relation to statistical probabilities. Many other tools and techniques have been developed since then, known by a long list of names. Quality developments over the years are summarized in Table 1.1. (A very good book on the history of quality leading up to and including the Six Sigma process is the book *Fusion Management: Harnessing the Power of Six Sigma, Lean, ISO 9001:2000, Malcom Baldrige, TQM and other Quality Breakthroughs of the Past Century.*[1]) A timeline for the history of quality, lean, and other related events is provided in Appendix N.

Table 1.1 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 revisions in 2000, 2008, and 2015, and now comprise ISO 9000 (definitions), ISO 9001 (requirements), and ISO 9004 (continuous improvement).
Reengineering	1996–1997	A breakthrough approach involving the restructuring of an entire organization and its processes.

Continued

Table 1.1 Some approaches to quality over the years. *(Continued)*

Quality approach	**Approximate time frame**	**Short description**
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 healthcare. 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 Chapter 1.
Lean manufacturing	2000–present	As described in Chapter 2.

Modern Six Sigma

Shortly after the Motorola Company achieved the Malcolm Baldrige National Quality Award (MBNQA) in 1988, they came calling to the Ford Motor Company to try to sell some new radios. The Ford purchasing department had just started a new process called the *supplier quality improvement* (SQI) initiative that was designed to work with external manufacturing suppliers from new design concept to launch of new vehicles. Ford had developed a *planning for quality* process using ASQ's *advanced quality planning* (AQP) and wanted to improve supplier quality delivered to the automotive assembly plants. This effort was instrumental in the development of what is now called *advanced product quality planning* (APQP), used in the automotive industry.

The Motorola sales team presented their newly developed methodology called Six Sigma, which was considered a key to achieving the MBNQA, to a Ford SQI senior quality engineer who was assigned to evaluate the Six Sigma methodology in relation to the Ford Q1 (Ford's top award, which is still available today) and Q-101 (forerunner of the QS-9000 and ISO/TS 16949 and the current IATF 16949) programs. The Ford SQI senior quality engineer liked what he saw except for one particular item: In the early days, a Six Sigma process was described as ±3 standard deviations ($C_p = 1.0$). The Ford requirement was $C_{pk} \geq 1.33$ for ongoing processes and $C_{pk} \geq 1.67$ for startup processes. (Note: Even as late as 1998, Mikel Harry's book *Six Sigma Producibility Analysis and Process Characterization* had a note on page 3-3 stating "Today, some organizations require $1.5 < C_p < 2.0$, or even $C_p < 2.0$.")[2] An interesting aside is that later discussions with Motorola technical individuals did confirm that the salespeople did not understand what they were presenting, and that inside Motorola the 6σ process was actually ±6 standard deviations, but this was well after the initial presentation, and Motorola lost the potential sale to Ford.

Six Sigma is a structured and disciplined process designed to deliver perfect products and services on a consistent basis. It aims at improving the bottom line by finding and eliminating the causes of mistakes and defects/deficiencies in business processes. Today, Six Sigma is associated with process capabilities of $C_{pk} > 2.0$ (some would say $C_p = 2.0$ and $C_{pk} < 1.5$), which are considered world-class performance (this allows for the 1.5 sigma shift factor). Remember that *sigma* is a statistical term that refers to the standard deviation of a process around its mean versus the methodology of problem solving that has been labeled 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.
- Continual effort to reduce variation in all processes within the organization.

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 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).

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*, *LSS*, or *Lean Six Sigma* 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 activities) and promotes work standardization and value stream mapping. Six Sigma practitioners should be well versed in both.

Quality Pioneers

Most of the techniques found in the Six Sigma toolbox have been available for some time thanks to the groundbreaking work of many professionals in the quality sciences. These and many others have contributed to the quality profession. Some of the key contributors include (in alphabetic order):

Subir Chowdhury is one of the new leaders in management thought and is being recognized by many companies and organizations as being on the forefront of customer satisfaction in today's business world. Dr. Chowdhury has written or coauthored a growing number of books on management with other top quality and business leaders. The following themes are found in most of his books:

- Problems can be prevented through continuous improvement—getting it right the first time—and should be the goal of every organization as it designs, develops, and deploys products and services.
- Quality must be the responsibility of every individual in all organizations. The "quality mission" cannot be delegated to one group or individual. It cannot be a "top down" management process. For quality to be robust and sustainable, everyone in the organization must not only accept it, they must believe in it.
- Quality begins at the top. Without the commitment of leadership—and without them demonstrating that commitment in every aspect of their own lives—initiatives will stall or fail over time.
- Everyone has a stake in quality. Not only must quality involve everyone all the time, but in order to achieve robust and sustainable results, everyone must have a stake in its implementation and

continuous improvement through peer reinforcement and other methods.

- Quality is a balance of people power and process power, where "people power" takes into account the role of the quality mindset—approaching quality with honesty, empathy, and a resistance to compromise. Process power is about solving problems, developing ideas and solutions, and then perfecting those ideas and solutions.
- Improving quality using a cookie-cutter managerial approach does not work. Every organization is unique. Every problem has different issues. Every individual brings different knowledge, skills, and abilities. Therefore, the methods, processes, and procedures used to solve quality issues must be tailored to the specific situation.

One of Dr. Chowdhury's mentors was Philip Crosby. Some of Dr. Chowdhury's books show Crosby's influence, as can been seen in:

- *The Ice Cream Maker*. 2006. Doubleday, Random House.
- *The Power of LEO: The Revolutionary Process for Achieving Extraordinary Results*. 2011. McGraw Hill. LEO is an acronym that stands for *listen* (observe and understand), *enrich* (explore and discover), and *optimize* (improve and perfect).
- *The Difference: When Good Enough Isn't Enough.* 2017. Currency. The difference is summed up for leaders as using STAR in their lives: being Straightforward, being Thoughtful, being Accountable, and having Resolve.

Key contributions:

- Growing number of management books with focus on creating future products for Design for Six Sigma
- Working with top-level management teams to recognize the need for quality
- Thinkers 50 of London named Chowdhury the "quality prophet"

Philip Crosby wrote fourteen 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 fourteen steps to quality improvement as noted in the *Certified Manager of Quality/Organizational Excellence Handbook*[3] are:

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.
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.

Key contributions:

- Management theory for quality
- Engaged business executives in quality

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*[4] they 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.

Deming's "Seven Deadly Diseases" include:

1. Lack of constancy of purpose
2. Emphasis on short-term profits
3. Evaluation by performance, merit rating, or annual review of performance
4. Mobility of management
5. Running a company on visible figures alone
6. Excessive medical costs
7. Excessive costs of warranty, fueled by lawyers who work for contingency fees

Deming is known for many other quality processes, which led the Japanese in 1950 to create the Deming Prize (still a very coveted award in Japan for both individuals and companies). It can be argued that the Deming Prize is the foundation on which the U.S. Malcolm Baldrige National Quality Award and similar state and governmental awards are based.

Deming advocated that all managers need to have what he called a *system of profound knowledge*, consisting of four parts:

1. *Appreciation of a system*. Understanding the overall processes involving suppliers, producers, and customers (or recipients) of goods and services (today called the *process approach*).
2. *Knowledge of variation*. The range and causes of variation in quality, and use of statistical sampling in measurements (understanding that variation exists and how to recognize it).
3. *Theory of knowledge*. The concepts explaining knowledge and the limits of what can be known (how to learn). In the ISO Management System process, this is called "organizational knowledge." Other reference materials can be found under the heading of "Human Performance Technology."
4. *Knowledge of psychology*. Concepts of human nature (from the Maslow hierarchy and other literature, and application of the Platinum Rule [Do unto others as they want to have things done for them]).

Key contributions:

- Japan's reconstruction in the 1950s and 1960s; JUSE development of the Deming Prize

- Developments in sampling techniques—applied to census applications
- Management principles: Fourteen Points and Seven Deadly Diseases
- Red bead experiment
- Profound knowledge
- Transformation of American industry (1980s collaboration with Ford Motor Company and Michael Cleary of PQ Systems to teach basic quality principles through community colleges)

Armand Feigenbaum originated the concept of total quality control in his book *Total Quality Control*, published in 1951. In this book Dr. Feigenbaum coined the first use of the term *quality planning*—"The act of planning is thinking out in advance the sequence of actions to accomplish a proposed course of action in doing work to accomplish certain objectives. In order that the planner may communicate his plan to the person or persons expected to execute it, the plan is written out with necessary diagrams, formulas, tables, etc." 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

His contributions to the quality body of knowledge include:

- "Total quality control is an effective system for integrating the quality development, quality maintenance, and quality improvement efforts of the various groups in an organization so as to enable production and service at the most economical levels which allow full customer satisfaction."
- The concept of a "hidden" plant—the idea that so much extra work is performed in correcting mistakes that there is effectively a hidden plant within any factory.
- Accountability for quality. Because quality is everybody's job, it may become nobody's job—the idea that quality must be actively managed and have visibility at the highest levels of management.
- The concept of quality costs

Key contributions:

- Quality planning—became AQP
- Quality costs—the hidden factory

Kaoru Ishikawa published four books, is credited with developing the cause-and-effect diagram, and was instrumental in establishing quality circles in Japan. He worked with Deming through the Union of Japanese Scientists and Engineers

(JUSE) and was highly praised by Juran upon his passing. The *Certified Manager of Quality/Organizational Excellence Handbook*[5] summarizes his philosophy with the following points:

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

Key contributions:

- Japanese quality circles
- Ishikawa diagram (cause-and-effect diagram, fishbone diagram)
- Developed user-friendly quality control (concepts such as the 5S and other methods to allow operators to know when things are done correctly)
- High focus on internal customers

Joseph M. Juran pursued a varied career in management for over 60 years 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:

1. Create awareness of the need and opportunity for improvement.
2. Mandate quality improvement; make it a part of every job description.
3. Create the infrastructure: establish a quality council, select projects for improvement, appoint teams, provide facilitators.
4. Provide training in how to improve quality.
5. Review progress regularly.
6. Give recognition to the winning teams.
7. Propagandize the results.

8. Revise the reward system to enforce the rate of improvement.
9. Maintain momentum by enlarging the business plan to include goals for quality improvement.

The *Juran trilogy* is based on three managerial processes: quality planning, quality control, and quality improvement. Without change, there will be a constant waste; during change there will be increased costs; but after the improvement, margins will be higher, and the increased costs get recouped. Juran founded the Juran Institute in 1979. The Institute is an international training, certification, and consulting company that provides training and consulting services in quality management, lean manufacturing management, and business process management, as well as Six Sigma.

Key contributions:

- Pareto principle—"the vital few and trivial many"
- Management theory for quality
- Juran trilogy

Dorian Shainin started his career in 1936 as an aeronautical engineer and quickly started developing unique solutions to problems. He was mentored by Juran and others and became well known for his unique ability to solve the hardest of problems facing industry and other fields of endeavor. He is credited with saying, "Talk to the parts; they are smarter than the engineers." He was honored with a number of awards in the United States during his career and had a hand in the successful return of Apollo 13 to Earth.

Shainin developed many industrial statistical tools that collectively have become known as the Shainin System for Quality Improvement, or Red "X." Some of the specific tools he developed from his own experience and working with others include the lot plot, reliability service monitoring, pre-control (for control charts), component search, operation search, tolerance parallelogram, overstress testing, B vs. C, paired comparisons, isoplot, variable search, randomized sequencing, resistant limit transform, and rank order ANOVA.

Key contributions:

- Red "X"

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 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 ASQ's first honorary member.

On a day in May 1924, it is said that Dr. Shewhart presented a little memorandum of about a page in length to his boss (George Edwards). About a third of that page was given over to a simple diagram that we would all recognize today as a schematic control chart. That diagram, and the short text that preceded and followed it, set forth all of the essential principles and considerations that are involved in what we know today as process quality control.

Walter Shewhart was also credited by Dr. Deming as the originator of the plan–do–check–act (PDCA) cycle. This simple tool is the foundation of many problem-solving techniques used today. Deming later updated this to the plan–do–study–act (PDSA) cycle.

Key contributions:

- Father of statistical quality control
- Shewhart cycle—PDCA

D. H. Stamatis has probably published more on the quality profession than any other person. He has developed over 45 volumes relating to quality topics, including an entire series of books on Six Sigma. His *FMEA from Theory to Practice* is considered the foundation work on developing FMEAs for industry. His works are solidly rooted in literature searches, and he has used his skill and the power of the printed word to hone the quality profession.

Key contributions:

- First handbook dedicated to understanding and practical applications of FMEA
- Documented the development of Six Sigma to the present time

Genichi Taguchi was the author or coauthor of six books and received many honors in Japan and the United States for his extensive work in industrial statistics. He taught that any departure from the nominal or target value for a characteristic represents a loss to society. This is the primary function of the *Taguchi loss function*. Instead of long-term focus on specification limits as practiced by many engineering groups, he taught that focusing all efforts on reducing the variation around the target will yield much better results over time and satisfy the customers at much higher levels.

He also popularized the use of fractional factorial designed experiments and stressed the concept of robustness in the Taguchi design of experiments and the use of orthogonal arrays.

Key contributions:

- Taguchi loss function, used to measure financial loss to society resulting from poor quality
- The philosophy of *off-line quality control*, designing products and processes so that they are insensitive (“robust”) to parameters outside the design engineer’s control
- Innovations in the statistical design of experiments, notably the use of an outer array for factors that are uncontrollable in real life but are systematically varied in the experiment

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 1.1. 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 subsequent sections, and it is the foundation of the ASQ CSSGB BoK.

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 processes and other sources that will help in the continual improvement of process outputs. Figure 1.2 illustrates the relationships between systems, processes, subprocesses, and steps.

Process Inputs, Outputs, and Feedback

Figure 1.3 illustrates the application of a feedback loop to help in process control. It is often useful to expand on a process flowchart with more-elaborate diagrams. 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

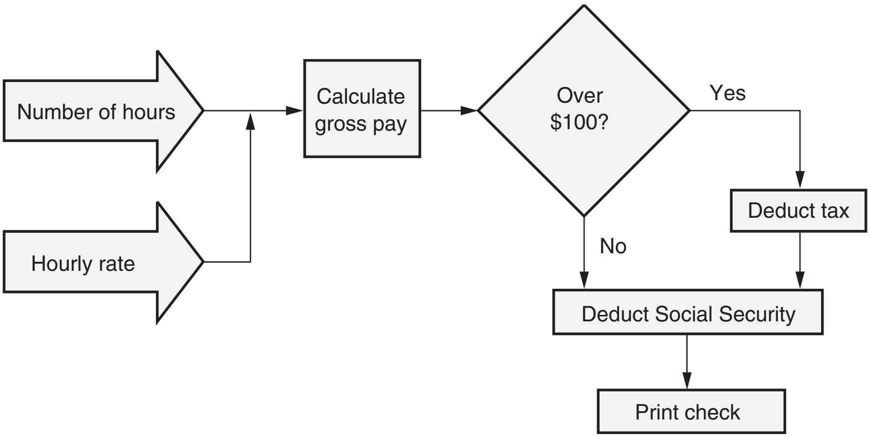

Figure 1.1 Example of a process flowchart.

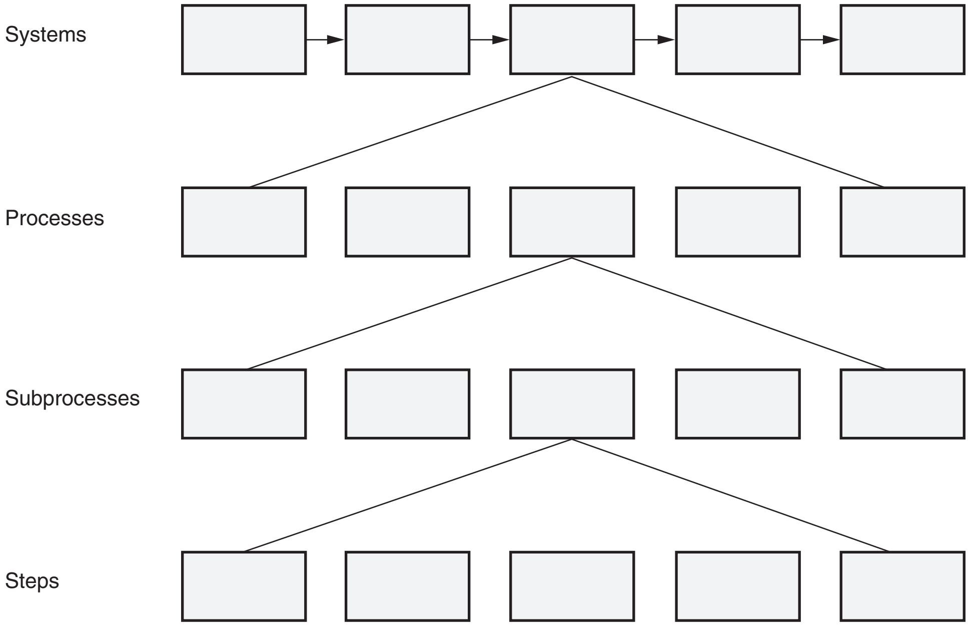

Figure 1.2 Relationships between systems, processes, subprocesses, and steps. Each part of a system can be broken into a series of processes, each of which may have subprocesses. The subprocesses may be further broken into steps.

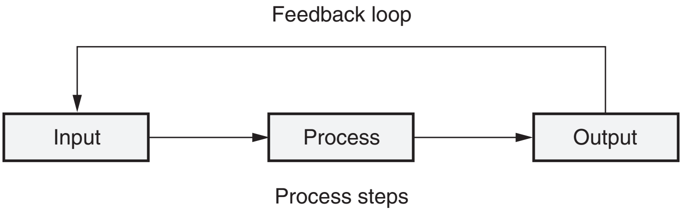

Figure 1.3 A feedback loop.

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.

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 Chapter 14. The third set of decisions entails the analysis of the data. The fourth set of decisions pertains to 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.

Significance of Six Sigma

Six Sigma is just the latest term for the more general concept of continual improvement. Continual improvement can be defined as the use of problem-solving techniques and quick deployment to implement improvements and then using process behavioral studies (Wheeler) to maintain the gains. Six Sigma has been described as a breakthrough system (Juran) and is being used in many organizations today in a variety of applications. Basically, Six Sigma is about collecting data on a process and using those data to analyze and interpret what is happening in that process so that the process can be improved to satisfy the customer (Kano and

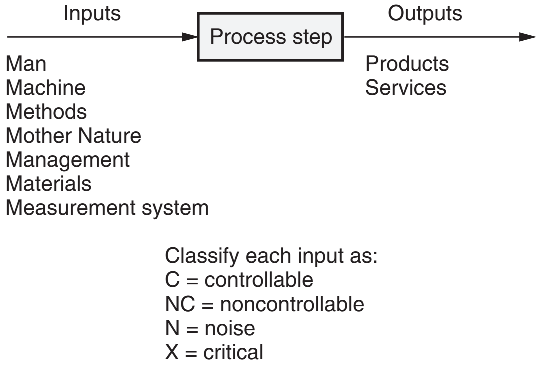

Figure 1.4 Categories of inputs to a process step.

Taguchi). A basic process can be defined as an input, transformation, and output. Six Sigma was first started at Motorola and was then developed more into what we know today at General Electric. By following a prescribed process, the entire organization starts to look at everything that it does in the light of reducing variation and reducing waste, with the result of increasing customer satisfaction. Customers could be anyone from the next person who uses the work we do (internal customer) to the ultimate customer who uses the products or services that our organization produces (external customer). To assist in this process, sometimes the supplier and customer will be added to the basic process definition listed above, creating the SIPOC identification: *suppliers*, *inputs*, *process*, *outputs*, and *customers*. This is used especially to help define the boundaries of what is to be studied.

For some, the idea of improving a process is a waste of time that should not be bothered with ("we are already working the hardest that we can"). But as Juran once said, "Changes creep up on us week by week, a little bit at a time. Over a year or two, there are 50 or 100 of these bits, which amounts to quite a bit. The skills of the men have not necessarily kept pace, and we wake up to the existence of a wide gap."[6] This is one explanation for why accidents and product rejections happen in our shops. If the root cause is actually found for any accident or rejection of product or service, it will usually be traced back to many small changes that occurred either within our own organization or at our supplier.

By using Six Sigma methodologies, we will be able to find those bits of changes and decide which ones should be kept for process improvement and which ones need to be corrected. This process is not meant to be a quick fix (magic bullet) approach. The logical use of the tools over time will save us resources and effort in doing our daily jobs.

A Green Belt's Role

You will find in this process for solving problems a number of tools and methods that you may already be familiar with and a few that may be new to you. You may very well ask, "How is this any different from what we have been doing before?" The direct answer will need to be provided by your organization depending on the various programs that have already been tried. For many of us, this process will be part of an ongoing evolution of how we do our work. One of the main things that you should notice is that upper management will be more involved with your problem-solving efforts and in the everyday problems that are found in your work areas.

During the process, and while using this book, you will be able to reference the Six Sigma model for improvement. It has been shown and demonstrated that by using a model or road map, we can usually accomplish something more quickly than without a guide. Some organizations today use something called the *MAIC model*. They refer to this process as being able to do "magic" without the "garbage" (G) that we find in most operations. Many organizations have added a *define* (D) stage—identifying the process customers—thus making for the DMAIC model.

You may already have control plans, process sheets, standard operating procedures, or any number of other things that you use in your daily work. The use of the Six Sigma model for improvement should not replace anything that you are currently doing, but be used to review daily work to look for areas or methods of improving the process in light of what your customers want and need. Even though we are doing the same things that we might have done before, do our customers still want the same things from us?

We are entering a journey of continual improvement that can involve our work and our lives. Some of us have been on this journey for some time, while others may be just starting. The process involves using what Deming refers to as *profound knowledge*: appreciation for a system, knowledge about variation, theory of knowledge, and psychology. Through the Six Sigma methodology and using the Six Sigma model for improvement, we should see things around us work better and satisfy our customers more.

Potential Tasks

Your organization may already be using something called Six Sigma or some other method (for example, quality operating system [QOS], continuous improvement [CI], total quality management [TQM], process improvement [PI], or some other name). As an operator or owner of a process, you will be asked by your supervisors or management to help implement improvement of the process(es) that you work with. Your challenge will be to look at the process both for the simple improvements that you may already know need to be made (preventive maintenance, cleanliness, parts wearing out, and so on) as well as to assist in measuring certain factors about the process to investigate better ways of performing the process.

You will be asked to use the tools in this book, and maybe others, to study your work and process(es) to look for improvement ideas and to implement those ideas. You may already be familiar with some of these tools, and the challenge will be in how to use them, possibly in new ways, to make the changes that will help your company stay in business in today's fiercely competitive world. We no longer compete only against others within our own country, but against others from countries around the world. How can they do a better job than us, ship the parts that we make, and sell them to our customers faster, better, and cheaper than us? This is the question that should be on your team's mind.

Many of us have found that by using a model or framework we can do things more simply—a picture is worth a thousand words. This is also true when trying to improve processes. Dr. Ishikawa gave us a road map to follow when first looking at a process that needs to be improved. The words may not make much sense right now, but as you work with process improvement (as you work through the DMAIC process), you will come to understand the importance of what is said here:

1. Determine the assurance unit (what is to be measured).
2. Determine the measuring method (how it will be measured).
3. Determine the relative importance of quality characteristics (is this key to our process?).
4. Arrive at a consensus on defects and flaws (does everyone agree on good and bad quality?).
5. Expose latent defects (look at the process over time).

6. Observe quality statistically (use process behavior charting).
7. Distinguish between "quality of design" and "quality of conformance."

After we know what we can change (quality of conformance) versus what we cannot change right now (quality of design—this is left to *design for Six Sigma* [DFSS]), we can start working on our processes. Many operators start out viewing this effort as only more work, but many will find that doing these studies will actually save them a lot of time and grief in the future as things start to improve and machines start to work better. One question to ask yourself now is, how often does your process slow down or stop due to something not working the way it should? Or, is the output ever scrapped by someone down the line (including at your external customers) because something did not happen right at your operation?

Be willing to experiment with the tools and look for ways of applying them to the work and processes to learn as much as you can about how a process operates so that you can modify it as appropriate to give the customers the best output that is possible.

DMAIC Model

The DMAIC model stands for *define*, *measure*, *analyze*, *improve*, and *control* and is very similar to the PDSA or PDCA model that you may already be using.

A key factor in each step is for management to allow the time and resources to accomplish each of the phases to strive for continual improvement. This is one of the driving forces that makes Six Sigma different from other quality improvement programs. The other driving forces include getting everyone in the organization involved, getting the information technology group to assist in supplying data more quickly for everyone, and getting financial data in the form of cost of quality analysis.

Everyone will be asked to get involved with the Six Sigma model and look for continual improvement opportunities in their work areas. Basically, you will do the following in each step:

Define: Identify the issue causing decreased customer satisfaction.

Measure: Collect data from the process.

Analyze: Study the process and data for clues to what is going on.

Improve: Take action, based on the conclusions obtained from the analysis performed in the previous step to change the process for improvement.

Control: Monitor the system to sustain the gains.

A number of tools and methods can be used in each of the steps of the DMAIC model. This is only a quick overview of many of these items. More detailed information can be found in the references, on the Internet, or probably in the quality office of your organization. The DMAIC model uses the following:

Define

Management commitment—PDCA

SIPOC (suppliers, inputs, process, outputs, customers)

Define the problem—five whys and how

Systems thinking

Process identification

Flowchart

Project management

Measure

Management commitment—PDCA

Identify a data collection plan

Measurement systems analysis (MSA)

Collect data—check sheets, histograms, Pareto charts, run charts, scatter diagrams

Identify variability—instability, variation, off-target

Benchmark—start by setting the current baseline for the process

Start cost of quality

Analyze

Management commitment—PDSA

Continual improvement

Preventive maintenance

Cleanliness—5S

Benchmark—continue process

Central limit theorem

Geometric dimensioning and tolerancing (GD&T)

Shop audit

Experiments

Improve

Management commitment—PDSA

Process improvement

Organizational development

Variation reduction

Problem solving

Brainstorm alternatives

Create "should be" flowcharts

Conduct FMEA

Cost of quality

Design of experiments

Control

Management commitment—SDCA

Control plan (CP)—manufacturing controls

End-to-end control plan—administration controls

Dynamic control plan (DCP)

Long-term MSA

Mistake-proofing

Process behavior charts

Update lessons learned

Many will find this process very exciting as they will have the tools and methods to demonstrate the improvements that they are helping the organization to achieve. There have been times in the past when an employee tried in vain to tell a supervisor that something was wrong with a machine or process. Now we have the means to not only tell but show and demonstrate what needs to be done. Following this process creates a road map for continual improvement that once started is a never-ending journey. These tools and methods have proven themselves to be useful everywhere: from shop floors to front offices, from schools to hospitals, and even in churches or at home.

The Six Sigma Road Map

As we prepare for the Six Sigma journey, here is a quick view of the suggested map that we can follow:

1. Recognize that variation exists in everything that we do; standardize your work.
2. Identify what the customer wants and needs. Reduce variation.
3. Use a problem-solving methodology to plan improvements.
4. Follow the DMAIC model to deploy the improvement.
5. Monitor the process using process behavior charts.
6. Update standard operating procedures and lessons learned.
7. Celebrate successes.
8. Start over again for continual improvement—PDSA/SDCA.[7]

Cost–Benefit Analysis (Cost of Quality, Quality Cost, Cost of Poor Quality, Cost of Current Quality)

This is a financial tool that should be used to report how quality levels are being sustained in the target process within an organization. Many things that are worked on throughout the shop can be classified into one of four categories: *prevention costs*, *appraisal costs*, *internal failure costs*, or *external failure costs.* However, not all expenses of the company are used, only those that relate in some way to the products or services that are shipped to customers. The real power of this tool is not so much that you use the exact or "right" measures for each expense, but that you look at trends over time to see what you are doing. You want to find out what the *total cost* is to provide your customers with products and services (see Figure 1.5). Traditionally, when cost of quality is first calculated for an organization, a picture such as Figure 1.5 emerges. Part of the reason for this is that many accountants and managers have not been taught about this tool in their formal education, nor does any governmental or professional organization require the reporting of financial data in this format.

On the other hand, organizations that have learned to use the cost–benefit analysis of quality cost, as called for in Six Sigma, are typically very surprised at the amount of waste that is being produced. By focusing on reducing prevention and appraisal costs, initial overall cost may rise; however, failure costs (internal and external) will slowly start to come down. This will not happen overnight and may take years, in stubborn cases, to show improvement as old products work their way out of the customer system. The end goal will be to have total cost of quality lower than when you started the Six Sigma process.

No one should be blamed for the poor results of the first round of measurements. It is important to look at these numbers as a benchmark to measure improvement from. The results of the numbers should be made available to everyone so

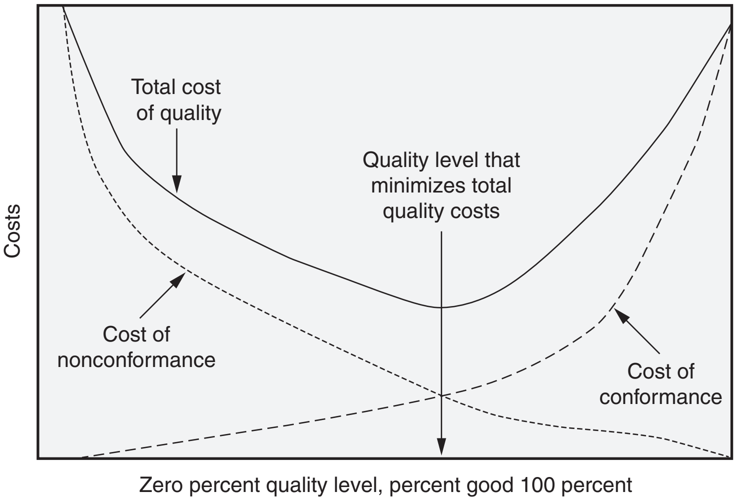

Figure 1.5 Traditional quality cost curves.

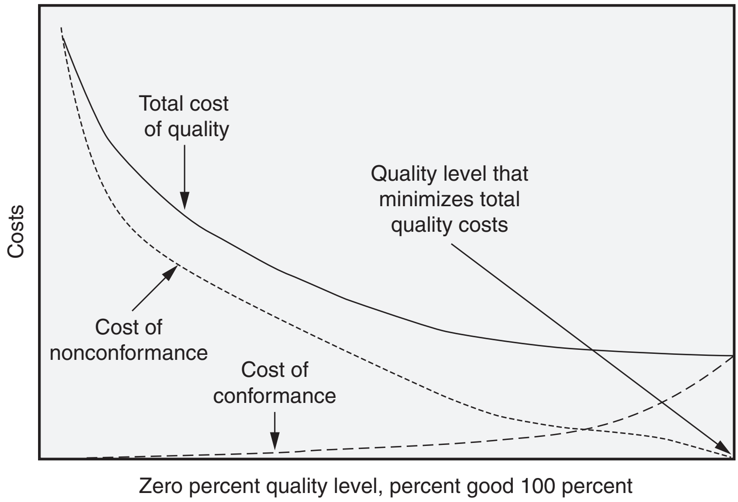

Figure 1.6 Modern quality cost curves.

that ideas can be generated as to what can be done and how. Remember the old management adage: "What gets measured gets done!" Thus, if everyone knows that management is watching the numbers on cost of quality, things should start to improve.

The ultimate goal is to change the overall picture to look like Figure 1.6. As an organization continually improves their products and services, they will see an overall reduction in total cost to manufacture and produce products and services.

ORGANIZATIONAL GOALS AND SIX SIGMA PROJECTS

Identify the linkages and supports that need to be established between a selected six sigma project and the organization's goals including SMART goals, and describe how process inputs, outputs, and feedback at all levels can influence the organization as a whole. (Understand)

Body of Knowledge I.A.2

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 shown 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, establishes 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 others 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 DFSS guidelines.

The project selection criteria are always a key element to 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, and increases in sales and/or profit. Other things being approximately equal, the projects with the greatest contributions to the bottom line receive the highest priority.

The formula for expected profit is

$$\text{EP} = \Sigma \text{ Profit} \times \text{Probability}$$

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 means that consideration 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 is called *suboptimization.* Changes in a system may optimize individual processes but suboptimize the system as a whole.

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 ≈ 0.474, and the probability of losing is 20/38 ≈ 0.526. In table form:

Outcome	Profit	Probability	Profit × Probability
Win	$1	.474	$0.474
Loss	–$1	.526	–$0.526
Expected outcome = –$0.052			

Continued

Continued

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 $3M. Previous experience indicates that the probability of getting customer A only is between 60 percent and 70 percent, and the probability of getting customer B only is between 10 percent and 20 percent. The probability of getting both A and B is between 5 percent and 10 percent.

One way to analyze this problem is to make two tables, one for the worst case and the other for the best case, as shown in Table 1.2.

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

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 1.7).

Table 1.2 Risk analysis table.

	Worst case profit			**Best case profit**		
Outcome		**Probability**	**Profit × Probability**		**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		

Strengths: High-quality product Monthly quantity commitment Tooling cost by customer Just-in-time concepts Online interface Product mix	**Weaknesses:** Pricing Union plant High employee turnover Aging equipment—downtime issues
Opportunities: Potential industry leadership More growth Long-term contract	**Threats:** Competition from startups Labor force Union plant Unstable market Unstable labor force

Figure 1.7 A format for SWOT analysis.

Task/objective	**S**	**M**	**A**	**R**	**T**
Reduce overtime for clerical staff by 15% by the end of the 3rd quarter	X	X	X	• Training • Process mapping • Office schedule • Electronic filing	12 months
Recruit five nursing assistants for the vaccination program by July 15	X	X	Discuss at December senior management meeting	• Hire tickets • Salary budget • Available talent pool	8 months
Enroll the new quality improvement coordinator into team training for 4th quarter	X	X	X	• Training budget • Appropriate class • Travel funds • Time away from current duties	2 months
Visit three substance program community partners each month between December and July	X	X	X	• Director and health officer schedule • Travel budget • Agency car	5 hrs/ month
Obtain two additional grants totaling $85K for toxic waste cleanup by 2nd quarter next year	X	X	Few funding sources for toxic waste cleanup	• Grant writer • Chemical analysis equipment • Chemist	3 months
	Specific	*Measurable*	*Attainable*	*Resources*	*Time*

Figure 1.8 SMART matrix example.

Examples of suboptimization:

- The resources invested in improving process A might be more profitably invested in process B.
- The throughput rate of a process increases far beyond the ability of the subsequent process to handle it.

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. A different loading style/arrangement might be more expensive to the distribution center but would result in significant cost reduction for the entire system.

An addition to the ASQ CSSGB 2022 BoK deals with the use of SMART goals (or objectives), which has become increasingly popular for project management events. SMART is an acronym that has evolved since the early 1980s and most commonly stands for: Specific, Measurable, Attainable (or Achievable), Relevant, and Time (or Time-Bound).

In the early phase of planning for your Six Sigma project, creating a set of SMART goals (see Figure 1.8) will help set boundaries and define steps in the DMAIC process for your team to achieve. These goals help to prevent scope creep and set up targets that can be used in Toll-Gate Reviews (discussed later) to help ensure that the goals have been met. It is a well-known fact that setting measurable goals at the early stages of a project (as well as in your life goals) usually goes a long way in helping to ensure achievement of desired results.

ORGANIZATIONAL DRIVERS AND METRICS

Recognize key business drivers (profit, market share, customer satisfaction, efficiency, product differentiation, key performance indicators (KPIs)) for all types of organizations. Understand how key metrics and scorecards are developed and how they impact the entire organization. (Understand)

Body of Knowledge I.A.3

Key Drivers

All organizations depend heavily on the measurement and analysis of performance. Such measurements should not only derive from business needs and strategy, but they should also provide critical data and information about key processes, outputs, and results. Several types of data and information are needed for performance management. A number of key drivers form the backbone of any business's effort to present performance information to executives and staff. These include customer, product, service, operational, market, competitive, supplier, workforce, cost, financial, governance, and compliance performance. A major consideration in performance improvement and change management involves the selection and use of performance measures or indicators. The measures or indicator that one selects must best represent the factors that lead to improved customer, operational, financial, and ethical performance. A comprehensive set of measures or indicators tied to customer and organizational performance requirements provides a clear basis for aligning all processes with one's organizational goals.

Voice of the Customer (VOC)

One of the key organizational drivers is customer and market knowledge—the ability of an organization to determine the requirements, needs, expectations, and preferences of customers and markets. Also necessary are the relationships with customers and the ability to determine the key factors that lead to customer acquisition, satisfaction, loyalty, and retention, and to business expansion and sustainability. The *voice of the customer* (VOC) is the process for capturing customer-related information. This process is proactive and continuously innovative in order to capture stated, unstated, and anticipated customer requirements, needs, and desires. The goal is to achieve customer loyalty and to build customer relationships, as appropriate. The VOC might include gathering and integrating survey data, focus group findings, Web-based data, warranty data, complaint logs and field reports, and any other data and information that reflect the customer's purchasing and relationship decisions.

Balanced Scorecard

Many business professionals advocate the use of a balanced scorecard type of approach for the selection of project metrics as a method for ensuring that the project meets both customer and business needs. The balanced scorecard approach includes both financial and nonfinancial metrics, as well as lagging and leading measures across four areas or perspectives: financial, customer, internal processes, and employee learning and growth. Lagging measures are those that are measured at the end of an event, while leading measures are measures that help achieve objectives and are measured upstream of the event.

This new approach to strategic management was developed in the early 1990s to help managers monitor results in key areas. The concept was illustrated by Drs. Robert Kaplan and David Norton, who named this system the *balanced scorecard.* Recognizing some of the weaknesses and vagueness of previous management approaches, the balanced scorecard approach provides a clear prescription as to what companies should measure in order to "balance" financial results.

The balanced scorecard is not only a measurement system, but also a management system that enables organizations to focus on their vision and strategy and translate them into actions. It provides feedback on both internal business processes and external outcomes in order to continuously improve strategic performance and results. When fully deployed, the balanced scorecard transforms strategic planning from an academic exercise into the nerve center of the enterprise. Most balanced scorecard metrics are based on brainstorming; however, the brainstorming approach may have limited success in establishing sound metrics that maintain a good balance between lagging and leading measures.

Scoreboard/Dashboard

A *scoreboard*, or *dashboard*, is a visual representation that gives personnel a quick and easy way to view their company's performance in real time. The dashboard should be critical in assisting an employee to predict sales, cash flow, and profit, and gain clarity on the performance and direction of the company. In addition, it should be a critical decision-making tool used in the day-to-day operation of the firm that empowers employees and business owners to make the best decisions for their respective departments that will drive cash flow and profit.

There are three main steps to consider in building an effective dashboard. First, we should know the averages and benchmarks for our industry. Second, we should know what our historical performance has been on these same averages and benchmarks. And third, we have to develop what many call a *balanced scorecard* that comprehensively examines the whole company, not just one or two parts.

Key Performance/Process Indicator (KPI)

Depending on the consultant you talk with, you might get the same definition for three different titles: *key process indicator*, a *key performance indicator*, or a *process performance indicator*. It is hard to distinguish between these three terms. However, for the Green Belt, you will be functioning generally at the levels in an organization that will understand the term *key process indicator*. Thus, a *KPI* is a quantifiable measurement, which is agreed to beforehand, that reflects the critical success factors of a department or group within your organization. They will differ depending on the company.

In nearly all cases of measuring performance of a process, there are usually a lot of things that could be tracked depending on where you are in the process. If you think of any major sporting event, the final score is only one measure of a team's performance. There are many key measures that, when all added up, contribute to what the outcome of the game will be. It's the same in any organization; your biggest challenge may in fact be in trying to sort through all of the data that are being collected to identify the key measures that need to be tracked in order to obtain the desired outcome for the organization. Your management team should have already thought this through and should be able to give direction on what measures you will need to track in your projects.

Chapter 2

Lean Principles in the Organization

LEAN CONCEPTS

> Define and describe lean concepts such as theory of constraints, value chain, flow, takt time, just-in-time (JIT), Gemba, spaghetti diagrams, and perfection. (Apply)
>
> **Body of Knowledge I.B.1**

Lean has been referred to by many names: lean manufacturing, lean office, lean enterprise, lean production, flexible mass production, and others. Toyota is usually credited with creating the concept of lean under their Toyota Production System (TPS) as far back as the 1950s; however, they credit having learned the process from the Ford Motor Company.[1] Three concepts are fundamental to the understanding of lean thinking: value, waste, and the process of creating value without waste. In today's variation of the TPS, some like to identify the 8*Ps of lean thinking* as purpose, process, people, pull, prevention, partnering, planet, and perfection.

Essentially, lean is centered on making obvious what adds value by reducing everything else. Some people only look at lean as a set of tools to apply within the organization to eliminate waste (Muda). However, the TPS is much more and involves the developing of a culture in an organization that promotes the continual improvement philosophy and the development of all people in the organization (see Figure 2.1). Far too many systems and management practices in a typical organization prevent operators from doing their best work to satisfy the customers.[2]

One of the more dramatic examples of success using the TPS was the joint venture between Toyota and General Motors at New United Motor Manufacturing, Inc. (NUMMI) in an old GM Fremont, California, plant that operated from 1984 to 2010. The success of the NUMMI plant was demonstrated by literally going from being the worst plant in the GM system to being one of the top plants in less than two years. Part of the initial agreement was that the GM management team would follow the direction of Toyota management and learn the TPS process.

There are a number of books, articles, and web pages that explain the TPS in great detail and are available for more research as your need presents itself. Following are some of the basic tenets of the TPS process.

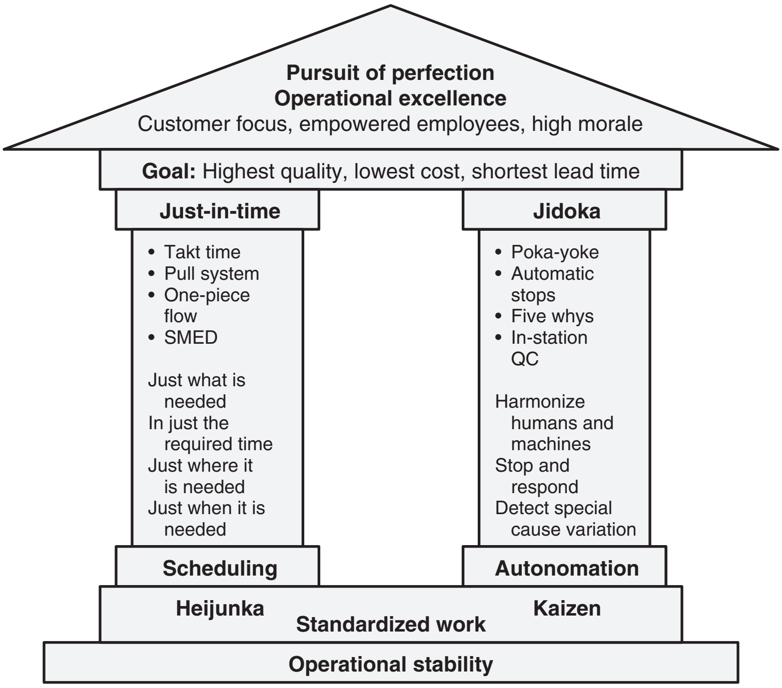

Figure 2.1 TPS house.

Value

The single most important concept that has been brought to awareness in the business community in recent years is *value.* Value is defined by the customer based on their perception of the usefulness and necessity of a given product or service. An excellent industrial video to view on this topic is *Time, the Next Dimension of Quality*, available through CRM Learning at www.crmlearning.com.

While Japanese-made cars and German-made cars are sold in the same markets, some customers prefer Japanese-made for their quality, reliability, resale value, and fuel efficiency. German-made cars can satisfy some of those same expectations and additionally offer a pride of ownership attached to the carmaker. There is a segment of customer that prefers German-made cars for these very reasons. Thus, customers define the value of the product. American carmakers build trucks and vans sturdy enough to handle tough jobs. Some American cars, trucks, and vans are comparable in quality and reliability to the Japanese and German competition. They also have built-in customer loyalty. There is a segment of customer who will buy American-made vehicles for these very reasons.

Once the concept of value is understood, the target cost for the product or service can be determined. According to Womack, this target cost is a mixture of current selling prices of competitors and examination of elimination of waste by lean methods.[3]

Lean experts define a process step as value-added if:

- The customer recognizes the value

- It changes (transforms) the product
- It is done right the first time

Some activities performed in operations do not change the form or function of the product or service, and the customer is not willing to pay for these activities. These activities are labeled *non-value-added*. A classic example is *rework*. The customer expects to pay for the printing of a document, for instance, but does not want to pay for corrections caused by errors of the supplier. A key step in making an organization more lean is the detection and elimination of non-value-added activities. In searching for non-value-added activities, the operative guideline should be "question everything." Steps that are assumed to be necessary are often ripe with opportunities for improvement. Team members not associated with a process will often provide a fresh eye and ask the impertinent questions.

There are, of course, gray areas where the line between valued-added and non-value-added may not be obvious. One such area is inspection and testing. A process may be so incapable that its output needs to be inspected to prevent defective parts from entering downstream processes. It could be argued that this

14 PRINCIPLES OF "THE TOYOTA WAY"[4]

1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.
2. Create a continuous process flow to bring problems to the surface.
3. Use "pull" systems to avoid overproduction.
4. Level out the workload (work like the tortoise, not the hare).
5. Build a culture of stopping to fix problems to get quality right the first time.
6. Standardized tasks and processes are the foundation for continuous improvement and employee empowerment.
7. Use visual controls so no problems are hidden.
8. Use only reliable, thoroughly tested technology that serves your people and process.
9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.
10. Develop exceptional people and teams who follow your company's philosophy.
11. Respect your extended network of partners and suppliers by challenging them and helping them improve.
12. Go and see for yourself to thoroughly understand the situation.
13. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.
14. Become a learning organization through relentless reflection and continuous improvement.

inspection is a value-added activity because the customer doesn't want defective products. The obvious solution is to work on the process, making it capable and rendering the inspection activity unnecessary. Most authorities would agree that this inspection is non-value-added. On the other hand, a gas furnace manufacturer must fire-test every furnace in order to comply with CSA requirements. Customers are willing to pay for the CSA listing, so this test step is a value-added activity. Studies have shown that an overwhelming percentage of lead time is non-value-added, much of it spent waiting for the next step. Yet, over the years, efforts to decrease lead time have often focused on accelerating value-added functions rather than reducing or eliminating non-value-added functions.

Some of the Top Lean Tools

5S (or 6S or 7S). 5S is a workplace organization method that can help improve the efficiency and management of operations. A process is impacted by its environment, as is the ability of personnel to respond to process change. Improvements in the general state of the work area, including access to hand tools, and so on, are an aid to process control. Especially critical here are the cleanliness, lighting, and general housekeeping status of any area where measurements are conducted since process control data are filtered through the measurement system. Example: A workbench cluttered with tools and accessories wastes the valuable time of skilled workers and causes distraction from work, resulting in poor quality. Similarly, an office table covered with disorganized files and papers can cause clerical errors and delays in processing. 5S is one of the first tools to apply in the path to achieving lean enterprise organizations.

The traditional sequence for 5S is:

> *Sort.* Remove unneeded items. Whether we're in the office or home, we tend to collect items that are very rarely needed or not needed at all. Over a period of time these items accumulate into a mess and make it less efficient to search for needed items, and sometimes even cause safety issues. The first step is sorting through the items as required and cleaning up the work area. Never-used items should be discarded immediately.
>
> *Set in order.* Arrange the required and rarely required items for ease of accessibility. The items that are required more often, like drawings, instructions, tools, safety goggles, and so on, are placed in designated and marked locations so that they cannot be placed elsewhere. In short, a place for everything and everything in its place. The rarely required items like machine manuals, shop floor layout plans, and so on, can be kept out of the way.
>
> *Shine.* This involves cleaning the work area and equipment. As simple as this may sound, many quality issues are uncovered through effective cleaning of the work area. Example: Cleaning of the inspection surface plate provides better measurement results, cleaning of the equipment work table provides for better movement, and cleaning of the floor prevents accidents. For some industries, like semiconductor manufacturing, cleanliness is mandatory and is measured in particle count.

Standardize. This involves developing checklists, standards, and work instructions to keep the work area in a clean and orderly condition. Under an ISO Management System umbrella, this can also include reviewing the JHA, JSA, or procedures.

Sustain. This is the most difficult step in 5S. Most organizations are initially successful in the first four steps, but sustaining the efforts and continuing them require support from management and empowerment of employees. Management needs to realize that this time is well spent and be willing to invest in the time. The time invested in 5S improves productivity and overall efficiency, and reduces accidents. Management should also empower the employees by allowing them to take ownership of their work areas.

An article was published by *Quality Progress* in October 2013 called "5S Shakeup: Three Secrets for Sustaining 5S Success" by John Casey.[5] Mr. Casey was a manager at the NUMMI plant and learned directly from Toyota the internal secrets of 5S. The article describes the secrets for typical North American organizations as:

1. Engage management on the cost savings to be achieved with 5S.
2. Establish visible scoreboards that include measures for cleanliness.
3. Once the scoreboards are in place, instead of starting with *sort*, the organization should focus on starting in step 4, *standardize*, so that people know how to change their scores.

Also note that some people add a sixth *S* (safety) and in healthcare (or other heavily regulated industry) a seventh *S* (oversight) (see Figure 2.2).

Andon. A visual feedback system (typically red/yellow/green stacked lights at the work site) that indicates the production status at any given time. It alerts operators and supervisors that assistance may be needed and empowers the employees to stop the process if an issue arises that is not considered good for quality.

With technology improvements, the monitoring of operations is becoming visible from various parts of the operation, and operators are being given ever earlier warnings that something may not be functioning as needed for normal operations.

A3. This tool was originally named after the metric size paper used to publish this reporting tool in Europe. The technique is used to give management a quick overview of key topics/issues of a project on one sheet of paper.[6] This can be used as an overview project template, status report template, or other quick update of the team or management. Examples of these forms are available as part of this handbook's online material.*

Bottlenecks. *See* theory of constraints.

Continuous Flow. Operations where work-in-process smoothly flows through the system with minimal (or no) buffers between steps of the operation. Developing a

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*https://asqassets.widencollective.com/portals/8ntnzkee/(H1469)SupplementalFiles-TheCertifiedSixSigmaGreenBeltHandbook,SecondEdition.

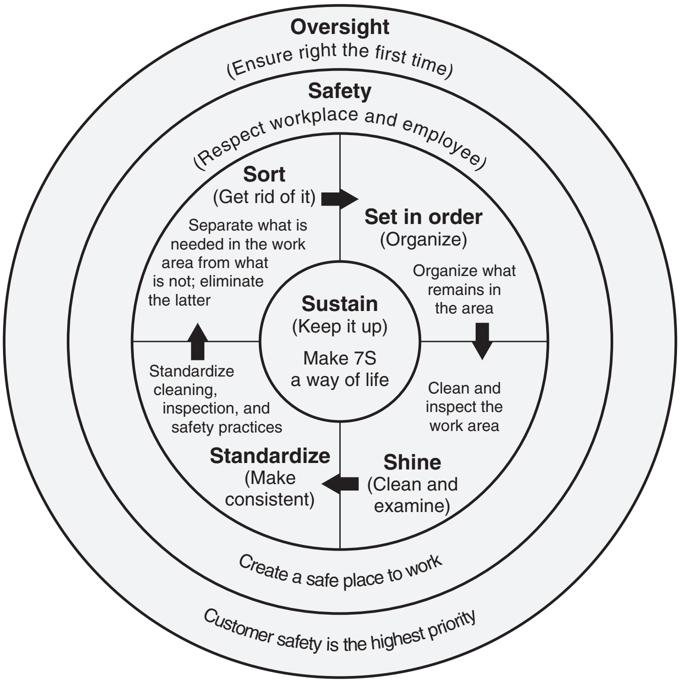


Figure 2.2 7S adaptation (Hirano).

continuous flow eliminates many forms of waste (for example, inventory, waiting time, transport, and overprocessing).

Gemba. The real place! A philosophy that reminds us to get out of our offices and spend time on the operations floor—the place where the real action occurs. In some management circles, this is called "management by walking around" (MBWA). This concept promotes a deeper and more thorough understanding of real-world operational issues by firsthand observation and by talking with employees doing the work. Another common phase for Gemba is "Look and See," and for the green belt, going to where the issue is occurring is very important as the starting point of any improvement project.

Heijunka. A form of production scheduling that purposely produces in much smaller batches by sequencing (mixing) product/service variants within the same process. This tends to reduce lead times (since each product or variant is produced more frequently) and lower inventory levels (since batches are smaller).

Hoshin Kanri. Otherwise known as *policy deployment*, its purpose is to align the goals of the company (strategy), with the plans of middle management (tactics), and the work performed on the operations floor (action). Also ensures that progress toward strategic goals is consistent and thorough and has the benefit of elimination of waste that comes from poor communication and inconsistent direction.

Jidoka (Autonomation). Within the TPS process, the concept is "why have a human do what a machine can do better," especially in the tedious, repetitive jobs that can cause injury over time. Sometimes called "intelligent automation" or "automation with a human touch," Shigeo Shingo has identified 23 stages between purely manual and fully automated work systems. To be fully automated, machines must be able to detect and correct their own operating problems, which is currently not cost-effective. He believed that 90% of the benefits of full automation could be gained by autonomation.

Just-in-Time (JIT). JIT is a production strategy promoted by Toyota, and now applied to many organizations, that strives to improve business return on investment by reducing in-process inventory and associated carrying costs. Kanban is one example of how this can be accomplished, but JIT extends throughout the organization to all aspects of product movement, including from suppliers. Basically, the belief is that storage of unused inventory is a waste of resources (no matter where in the system it exists). JIT inventory systems expose the hidden cost of keeping inventory, and help the organization devise new methods to manage the consequences of change. So in simple terms, JIT is an inventory management system that aims to have things available as needed in the production cycle without the need for guessing, work-in-process (WIP), or other characteristics of excessive inventories.

Kaizen (Continuous Improvement) versus Kaizen Events. *Kaizen* is a Japanese term for change for improvement, or improving processes through small incremental steps. Many people refer to this gradual change as *continual improvement*. Breakthrough improvement (which Juran refers to as big change) is described by another Japanese term, *kaikaku*.

Kaikaku is referred to in North America as a *kaizen event* or *kaizen blitz*. Hence, many practitioners often get confused with the interchangeable usage of kaizen and kaizen event. In lean implementation, kaizen events are used to provide quicker implementation results. Kaizen events are conducted by assembling a cross-functional team for three to five days and reviewing all possible options for improvement in a breakthrough effort. Management support is required for such initiatives. If the employees can't afford taking three to five days to improve a process constraint, then either the problem is unimportant or the organization requires more fundamental cultural adjustment before implementing lean.

Kanban (Pull System). A system is best controlled when material and information flows into and out of the process in a smooth and rational manner. If process inputs arrive before they are needed, unnecessary confusion, inventory, and costs generally occur. If process outputs are not synchronized with downstream processes, delays, disappointed customers, and associated costs may occur. A properly administered kanban system will improve system control by assuring timely movement of products and information. Kanban is implemented using a visual indicator called *kanban cards*. The card indicates the quantity to be replenished once the minimum level is reached.

An empty bin with a kanban card is the signal for production to pull material from the previous step. The kanban quantity is mathematically calculated and fine-tuned during practical implementation. Typically, organizations take a while to perfect kanban. Kanban is a more mature concept. It is important that other fundamentals of lean (5S, standard work, total productive maintenance [TPM], and variation reduction) are put in place before venturing into kanban. If not, frequent equipment failure and unstable or inconsistent processes will defeat the purpose of kanban, resulting in huge kanban sizes to shield against these uncertainties.

Muda. *See* waste

Overall Equipment Effectiveness (OEE). The concept of measuring how effectively a manufacturing operation is utilized was started in the 1960s and has developed into a calculation that multiplies the *availability*, *performance*, and *quality* of the process to create a percentage of overall effectiveness of the operation (A × P × Q = OEE). This is one of several measures available to track performance of the operation and is meant to be a benchmark for continual improvement efforts. A perfect 100% would indicate perfect production: manufacturing only good parts, as fast as possible, with no downtime.

PDCA or PDSA. Plan–do–check–act or plan–do–study–act.

Poka-Yoke. *Poka-yoke*, a Japanese term for mistake-proofing or error-proofing, is a method used to prevent errors. There are a number of examples in day-to-day life that use the mistake-proofing concept, such as electrical plugs and sockets that prevent plugging the wrong way, valves that shut once the maximum pressure is reached, fixtures that prevent loading the component in a wrong orientation, and so on. A window envelope is also a mistake-proofing method that allows users to see the letter with the right address sealed in. Similarly, there is detection-type mistake-proofing that alerts a user immediately after an error is made (to prevent further errors). Examples include car alarms that sound when the driver closes the door with the lights on, and an automatic gauging machine that alarms when an oversize or undersize part is produced.

Single Minute Exchange of Die (SMED). The goal of SMED is to provide a rapid and effective way of converting an operating process from running the current product to running the next product. The rapid changeover is key to reducing production lot sizes and thereby improving the flow of the system.

The economic lot size is calculated from the ratio of actual production time to changeover time, which is the time taken to stop production of a product and start production of the same or other product. If changeover takes a long time, then the lost production due to changeover drives up the cost of the actual production itself. The phrase “single minute” does not mean that all changeovers and setups should take only one minute, but that they should take less than 10 minutes (in other words, “single-digit minute”).

Standard Work. Basically, *standard work* is a tool that defines the interaction between man and machine in producing a part. It has three components: standard time, standard inventory, and standard sequence. Standard work helps in training new operators and reducing the variation in the process.

The basic idea is to make manufacturing methods and/or service processes consistent. Quality management systems like ISO 9001 provide a basic foundation to lean implementation by incorporating standard work as part of the controlled documentation. Further, by having standard work, equipment, tools, layout, methods, and materials are standardized and thus reduce variation in processes. A detailed process work instruction with all of the above can be a very useful standard work document.

Takt Time. Derived from the German word *taktzeit*, this refers to the baton that an orchestra conductor uses to regulate the speed, beat, or timing at which musicians play. The purpose of takt time is to precisely match production with demand. It provides the heartbeat of a lean production system. Takt time first was used as a production management tool in the German aircraft industry in the 1930s.

Takt time (also referred to as *beat time*, *rate time*, or *heart beat*) sets the pace of industrial manufacturing lines so that production cycle times can be matched to customer demand rates. Expected customer demand sets the pace at which you need to produce the product to deliver to those customers. Taking the total of customer demand into consideration, the production scheduling department determines what is needed when shipping to the customer. The production operations then set the pace to produce those parts/components/assemblies to match what is needed to ship to the customers.

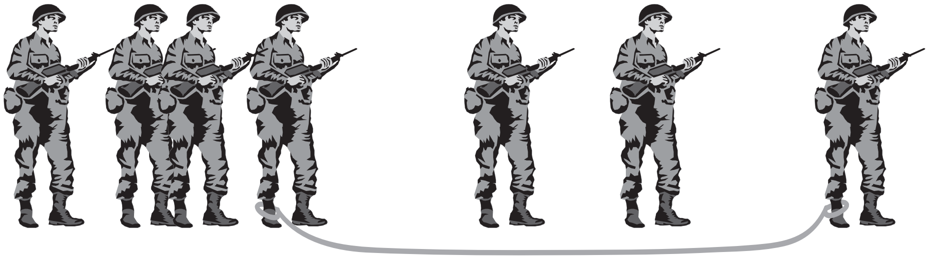
Theory of Constraints. *Theory of constraints* is a problem-solving methodology that focuses on the weakest link in a chain of processes. Usually, the constraint is the process that is slowest. Flow rate through the system cannot increase unless the rate at the constraint increases. The theory of constraints lists five steps to system improvement:

1. *Identify.* Find the process that limits the effectiveness of the system. If throughput is the concern, then the constraint will often have work-in-process (WIP) awaiting action.
2. *Exploit.* Use kaizen or other methods to improve the rate of the constraining process.
3. *Subordinate.* Adjust (or subordinate) the rates of other processes in the chain to match that of the constraint.
4. *Elevate.* If the system rate needs further improvement, the constraint may require extensive revision (or elevation). This could mean investment in additional equipment or new technology.
5. *Repeat.* If these steps have improved the process to the point where it is no longer the constraint, the system rate can be further improved by repeating these steps with the new constraint.

The strength of the theory of constraints is that it employs a systems approach, emphasizing that improvements to individual processes will not improve the rate of the system unless they improve the constraining process.

Drum–Buffer–Rope (DBR). Goldratt[7] introduced a squad of soldiers walking in single file as an analogy of a string of production processes. As the first soldier moves forward he receives unprocessed material, the fresh ground. Each succeeding soldier performs another process by walking on that same ground. As the last soldier passes over the ground, it becomes finished goods. So, the individual processes are moving over fixed material rather than the other way around. Lead time is the time that it takes for the squad to pass over a certain point. If each soldier moves as fast as he can, the lead time tends to lengthen, with the slower soldiers falling behind and holding up those behind them since passing is not permitted.

The system constraint is the slowest soldier. The ground can't be processed faster than this soldier can move. This soldier sets the drumbeat for the entire system. To avoid lengthening the lead time, a rope connects the lead soldier to the slowest soldier.



Now the squad moves along as a unit with minimum lead time and minimum work-in-process (WIP). If a soldier that is behind the slowest soldier happens to drop his rifle, he'll fall behind a little (especially if the sergeant notices it) but will be able to catch up since he is not the slowest soldier. This is analogous to a minor process problem at one station. If a soldier in front of the slowest soldier drops his rifle, the squad will not have to stop unless the slowest soldier catches up with the one in front of him. So, if the squad has a high tendency to drop their rifles, the rope must be longer. The length of the rope is the size of the buffer. In summary, to avoid long lead times and excess WIP, all system processes should be slowed down (via the rope) to the speed of the slowest process (the drum), with the amount of WIP (or buffer) determined by the dependability of the individual processes. For further explanation of these concepts see Goldratt's *Critical Chain.*

Total Productive Maintenance. If the lean enterprise implementation is to be sustained, the manufacturing or service equipment has to be reliable. In order to have reliable equipment, an organization has to maintain the equipment periodically. Preventive maintenance examples include changing oil at the required frequency, tightening loose parts, and watching for any visible or audible symptoms of failure. A comprehensive maintenance program may need a battery of maintenance technicians. This can be impractical and expensive. Hence, a *total productive maintenance* (TPM) program partners the maintenance technicians and line workers as a team to help each other reduce machine downtime. Management support is required to cross-train line workers to perform simple, basic maintenance and repairs. As the operators are trained to watch for symptoms of common failures, communication reaches maintenance technicians faster, thereby reducing downtime. Mature TPM programs use metrics like overall equipment effectiveness (OEE), which is a product of equipment availability, performance, and quality of output.

Value Stream. *See* value stream mapping later in this chapter.

Visual Factory. Visual factory provides visual identification of the status of material and information throughout the value stream. Examples of visual factory include providing status of material in/out at a raw material warehouse, showing units produced, units to complete order, and total produced by shift or day on a production display board, and indicating machine status with red, yellow, and green lights on the machine. Imagine that we need to find out the current status of a work order for a given customer. Often, this is achieved by talking to line supervisors, referring to logbooks, conducting internal meetings, and so on.

In short, if an employee can walk onto a shop floor and can tell which machines are running, what product is being produced, how many more are to be produced by customer, follow posted safety instructions, and report to management, that is an effective visual workplace.

Waste (Muda)

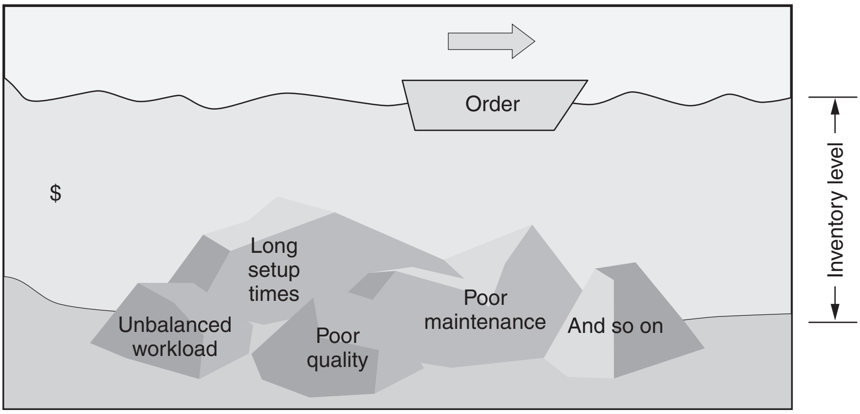
Some authors list seven or eight categories of waste, or *muda*, as it is referred to in some sources. These lists usually include overproduction, excess motion, waiting, inventory, excess movement of material, defect correction (rework), excess processing, and lost creativity (underutilization of resource skills). The following paragraphs examine the causes and results of each of these wastes.

Overproduction. Defined as making more than is needed or making it earlier or faster than is needed by the next process, the principal symptom of overproduction is excess *work-in-process* (WIP). Companies adopt overproduction for various reasons, including long setup times, unbalanced workload, and a just-in-case philosophy. One company maintains a six-month supply of a particular small part because the machine that produces it is unreliable. In some cases, accounting methods have dictated that machines overproduce to amortize their capital costs. All WIP should be continuously scrutinized for possible reduction or elimination.

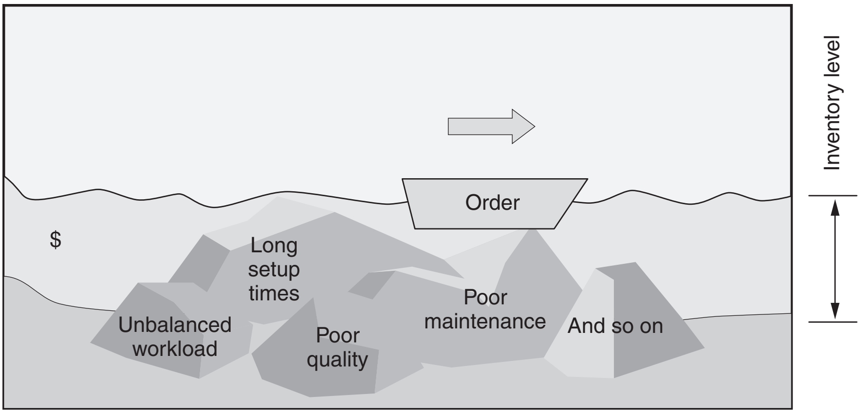
Excess motion. This can be caused by poor workplace layout, including awkward positioning of supplies and equipment. This results in ergonomic problems, time wasted searching for or moving supplies or equipment, and often in reduced quality levels. Kaizen events are effectively used to focus a small short-term team on improvements in a particular work area. The team must include personnel with experience in the positions involved, as well as those with similar functions elsewhere. In addition, it is essential to include people with the authority to make decisions. Such teams have made startling changes in two to five days of intense activity.

Waiting. Typically caused by such events as delayed shipments, long setup time, or missing people, waiting results in waste of resources and, perhaps more importantly, demoralization of personnel. Setup time reduction efforts and total productive maintenance are partial answers to this problem. Cross-training of personnel so that they can be effectively moved to other positions is also helpful in some cases. Most important, of course, is carefully planned and executed scheduling.

Inventory. When inventories of raw materials, finished goods, or work-in-process are maintained, costs are incurred for environmental control, record keeping, storage and retrieval, and so on. These functions add no value to the customer. Of course, some inventory may be necessary, but if a competitor finds ways to reduce costs by reducing inventory, business may be lost. One of the most tempting times to let inventory levels rise is when a business cycle is in the economic recovery phase. Instead of increasing inventories based on forecasts, the proper strategy is to synchronize production to increase with actual demand. Similarly, production or administrative functions that use more space or other resources than necessary increase costs without adding value. The common analogy of the sea of inventory, shown in Figure 2.3, illustrates how excess inventory makes it



a) The order floats through the system protected from unresolved problems by excess inventory.



b) When the protective inventory is reduced, problems emerge that must be solved. To reduce cost, we must fix the problems.

Figure 2.3 A sea of inventory often hides unresolved problems.

possible to avoid solving other problems. As the level of inventory is lowered, some problems will rear their ugly heads and need to be solved before further progress is possible.

Excess Movement of Material/Transportation. Large conveyor systems, huge fleets of forklifts, and so on, make production more costly and complex, and often reduce quality through handling and storing. Poor plant layout is usually to blame. Plants with function-oriented departments (all lathes together, all presses together, and so on) require excessive material movement. A better plan is to gather equipment together that is used for one product or product family. This may mean having a manufacturing cell contain several types of equipment requiring personnel with multiple skills. Many companies have had success with cells that form a C shape, as shown in Figure 2.4, because they can be staffed in several ways. If demand for the cell's output is high, six people could be assigned, one per machine. If demand is very low, one person could move from machine to machine, producing parts one at a time.

Defect Correction. This activity is non-value-added because the effort to fix the defective part is wasted. Typical causes of defects are poor equipment maintenance, poor quality system, poor training/work instructions, and poor product design. Lean thinking demands a vigorous look at these and other causes in order to continuously reduce defect levels.

Excess Processing/Overprocessing. This form of waste is often difficult to recognize. Sometimes, entire steps in the value chain are non-value-added. A steel stamping operation produces a large volume of parts before they are scheduled for painting. This may require the practice of dipping the parts in an oil solution to prevent rust as they wait to be painted. As the paint schedule permits, the parts are degreased and painted. The customer is unwilling to pay for the dip/degrease activities because they do not enhance the product. The best solution in this case is to schedule the pre-paint activities so that the parts are painted immediately upon

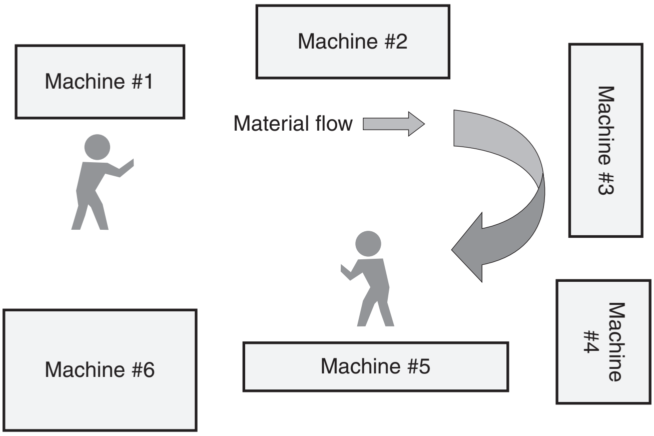


Figure 2.4 C-shaped manufacturing cell.

production. This may require smaller batch sizes and improved communication procedures, among other things.

The purpose of the grinding step that often follows a welding operation is to remove some of the weld imperfections. Improving the welding process may reduce or eliminate the need for grinding. The unnecessary grinding would be classified as excessive processing. Excess processing can occur in the office as well as on the plant floor. Information from customer purchase orders is sometimes entered into a database, and the order itself is filed as a backup hard copy to resolve any later disagreements. A recent study by one company revealed the fact that the hard copies, although they are occasionally pulled from files and initialed, stamped, stapled, and so on, really serve no useful purpose. The company now discards the purchase order once the information has been entered. The processes of filing, storing, and maintaining these records required one-half person performing non-value-added activity.

Additional Forms of Waste

Lost Creativity. This is perhaps the most unfortunate waste. Most manufacturing employees have ideas that would improve processes if implemented. Standard organizational structures sometimes seem designed to suppress such ideas. Union/management divides seem almost impossible to bridge. Lean thinking recognizes the need to involve employees in teams that welcome and reward their input. These teams must be empowered to make changes in an atmosphere that accepts mistakes as learning experiences. The resulting improved morale and reduced personnel turnover impact the bottom line in ways that no accountant has yet calculated. These are the nontangible benefits of lean thinking.

Perfection. The goal of eliminating muda is to strive for perfection. You now understand value-added activities. You also learned about various wastes, both hidden and explicit, in processes. By optimizing value-added activities and eliminating waste, your organization can aim toward achieving "perfection" in lean. This is not a one-time effort. This is a continual learning process.

Employee Demotivation. There is an old saying that hopefully you never have to experience: "Employees don't leave companies, they leave managers." Abraham Maslow created what is called the Hierarchy of Needs to help explain why people behave in business as they do.

The Hierarchy of Needs is usually viewed as a pyramid in this order (first item on top):

- Self-actualization needs: reaching full potential, fulfilling life's purpose
- Esteem needs: achievement, adequacy, confidence, recognition, appreciation
- Belongingness needs: acceptance, intimacy, friendship, trust
- Security needs: stable housing, safe schools, preventive medical care
- Fundamental needs: sleep, food, basic medical care

There can be any number of things at work that demotivate an employee, such as:

- Being apathetic
- Bullies in the workplace
- Culture
- Disorganization
- Failing to address company mission, vision, and values
- Feeling invisible in the workplace
- Going back on their commitments
- Hiring and promoting the wrong people
- Job insecurity
- Lack of clarity
- Lack of communication
- Lack of professional/personal development
- Lack of support
- Lack of trust or micromanagement
- Lack of workplace flexibility
- Letting accomplishments go unrecognized
- Low or unfair pay
- Making a lot of stupid rules
- Organizational direction – do not like the product or service
- Poor management style
- Tolerating poor performance
- Treating everyone equally

Lack of Effective Emergency Response Planning. ISO 22301 deals with Business Continuity, which many companies have failed to do adequately. See Chapter 6 for more information.

Spaghetti Diagrams (Spaghetti Map). A graphic tool intended to show the flow or path that people, products, or paperwork take during the course of normal operations. These can tend to look very messy for processes that have not gone through a process improvement procedure, especially when multiple people are involved in the process. One example that the audit did was to track the patient charts in a doctor's office. The staff had never seen the full extent of the process before (however, the two nurses recognized the paths that they had to run with the charts), and we created a simple flowchart for them to work on improving the process.

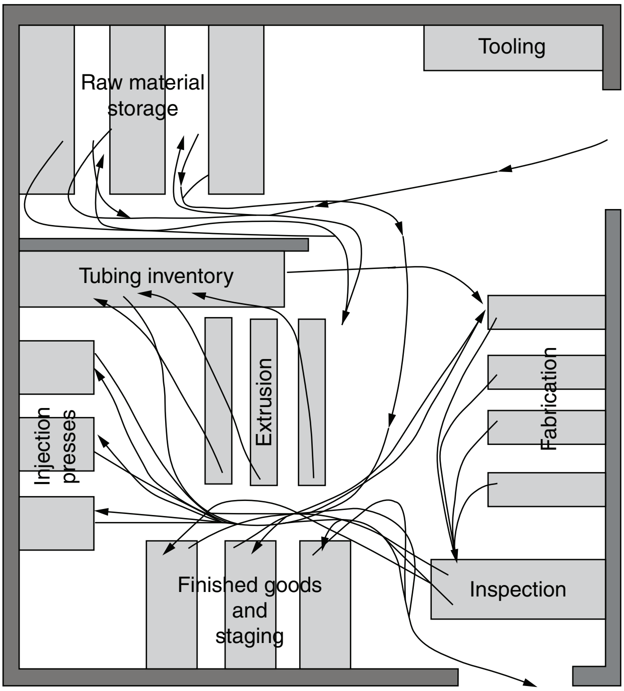


Figure 2.5 Spaghetti diagram showing the flow of materials through an operation.
Source: The Lean Handbook (Milwaukee: ASQ Quality Press, 2012).

VALUE STREAM MAPPING

> Use value-stream mapping to identify value-added processes and steps or processes that produce waste, including excess inventory, unused space, test inspection, rework, transportation, and storage. (Understand)
>
> **Body of Knowledge I.B.2**

Value Stream

A *value stream* is the series of activities that an organization performs, such as order, design, produce, and deliver products and services.[8] A value stream often starts from a supplier's supplier and ends at the customer's customer. Wastes are both explicit and hidden along this value stream.

The three main components of a value stream are:

1. Flow of materials from receipt of supplier material to delivery of finished goods and services to customers. Examples:
    - Raw material shipped weekly from supplier to the organization by truck
    - Movement of material from raw material storage to production process through to finished goods warehouse
    - Shipping of the finished goods to overseas customer via customs
2. The transformation of raw materials into finished goods or inputs into outputs. Example:
    - Production steps like cutting, shaping, forging, welding, polishing, and assembly
3. The flow of information required to support the flow of material and transformation of goods and services. Example:
    - Purchase order to supplier, internal work order, shipping notice

This concept is visually illustrated via a lean tool called the *value stream map.* This map uses simple graphics and icons to illustrate the movement of material, information, inventory, work-in-process, operators, and so on. Value stream mapping is a very powerful tool. The analysis subsequent to value stream mapping, called *value stream analysis*, can help uncover hidden wastes within the organization. An organization that effectively uses lean thinking and applies lean tools to reduce waste throughout the value stream and offer value to their customers is a *lean enterprise* organization.

Achieving a lean enterprise requires a change in attitudes, procedures, processes, and systems. It is necessary to zoom out and look at the flow of information, knowledge, and material throughout the organization. In any organization there are multiple paths through which products, documents, and ideas flow. The process of applying lean thinking to such a path can be divided into the following steps:

1. *Produce a value stream map*. This is also referred to as a *value chain diagram.* This diagram is described in detail by Rother and Shook.[9] It has boxes labeled with each step in the process. Information about timing and inventory is provided near each process box. Some symbols that are used on value stream maps are shown in Figure 2.6. Figure 2.7 shows an example of a value stream map.
2. *Analyze all inventory notes with an eye toward reduction or elimination*. Inventory tends to increase costs because:
    - Storage space may be expensive (rubber awaiting use in a tire factory is stored at 120 °F; wood inventory may need to be humidity-controlled).
    - Quality may deteriorate (rust, spoilage, and so on).

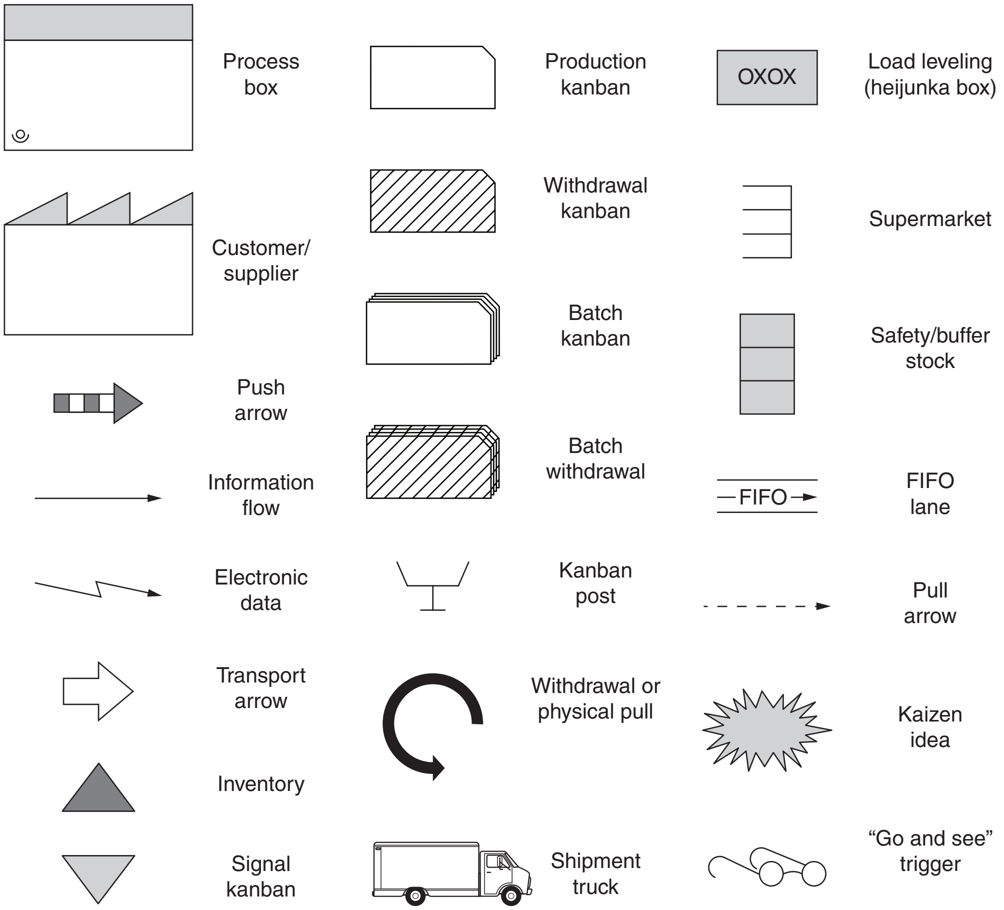


Figure 2.6 Common symbols used in value stream mapping.

- Design changes may be delayed as they work their way through the inventory.
- Money invested in inventory could be used more productively elsewhere.
- Quality problems that are not detected until a later stage in the process will be more expensive to correct if an inventory of defective products has accumulated.

One company refers to its racks of safety stock as the "wall of shame."

3. *Analyze the entire value stream for unneeded steps*. These steps are called non-value-added activities and are discussed in detail earlier in this section.
4. *Determine how the flow is driven*. Strive to move toward value streams in which production decisions are based on the pull of customer demand.

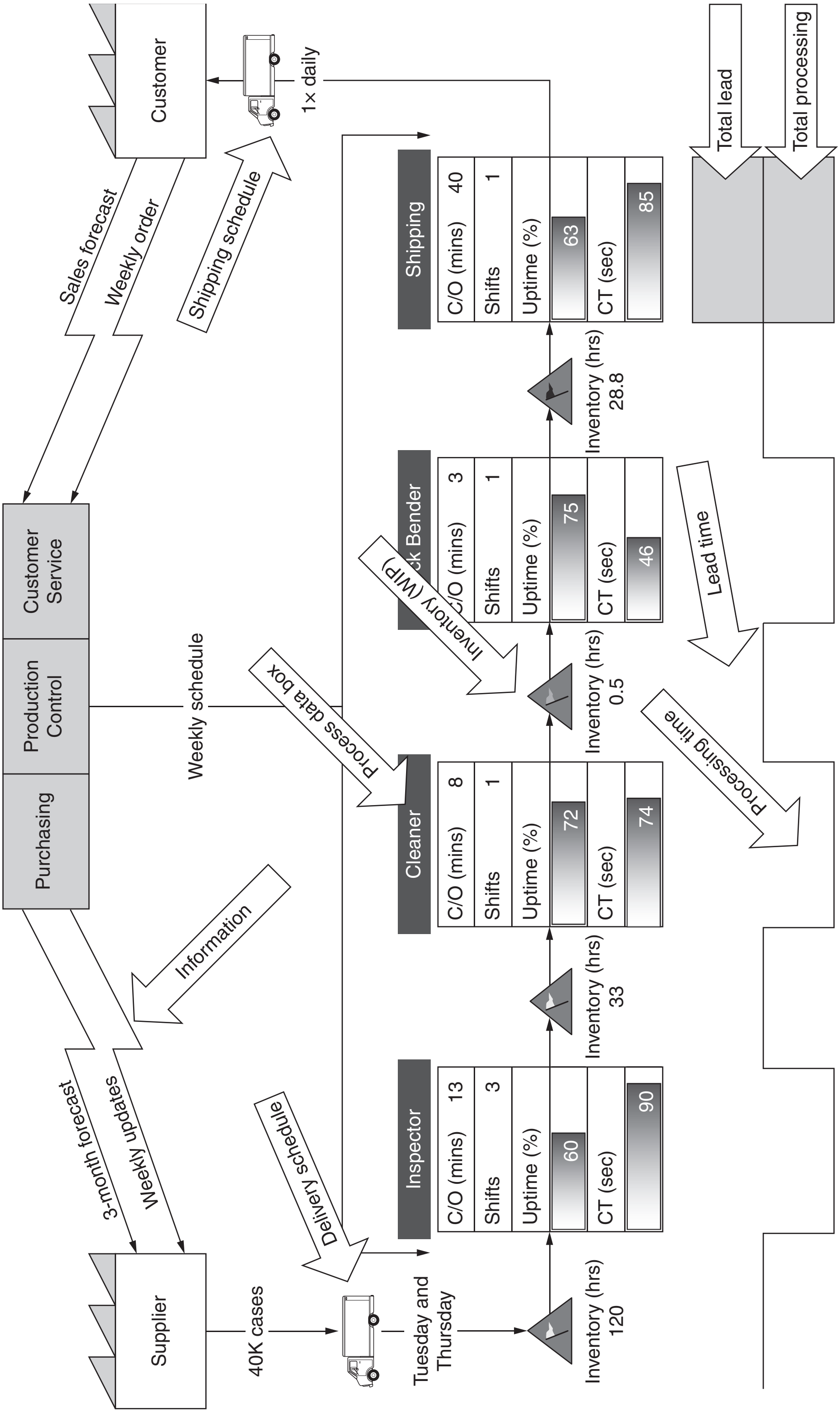


Figure 2.7 Value stream map example.

In a process where pull-based flow has reached perfection, a customer order for an item will trigger the production of all the component parts for that item. These components would arrive, be assembled, and delivered in a time interval that would satisfy the customer. In many situations this ideal has not been reached, and the customer order will be filled from finished goods inventory. The order should still, however, trigger activities back through the value chain that produce a replacement item in finished goods inventory before it is needed by a customer.

5. Extend the value stream map upstream into suppliers' plants. New challenges continue to occur regarding compatibility of communication systems. The flows of information, material, knowledge, and money are all potential targets for lean improvements.

When beginning the process, pick a narrow focus—don't try to boil the ocean, as the saying goes.

Chapter 3

Design for Six Sigma (DFSS) Methodologies

ROAD MAP FOR DFSS

> Distinguish between DMADV (define, measure, analyze, design, verify) and IDOV (identify, design, optimize, verify), and recognize how they align with DMAIC. Describe how these methodologies are used for improving the end product or process during the design (DFSS) phase. Understand how verification and validation are used to compare results against stated goals. (Understand)
>
> **Body of Knowledge I.C.1**

Organizations must extend their design beyond simple functionality and customer wishes to consider fulfilling other attributes and expectations. This holistic approach to design will result in a more stable and robust product that not only reflects customer preferences, but also is capable of being used and applied in the specified environment by the intended user. We typically refer to the use of Six Sigma in the design phase of product development as *design for Six Sigma* (DFSS).

Thus, the definition of DFSS includes:

- DFSS is a business/engineering strategic process that focuses on proactive design quality, rather than reactive design quality.
- DFSS is a systematic process to create produceable designs by reducing and managing variation in order to meet the “customer’s” expectations of quality/performance.

DMADV (define, measure, analyze, design, verify) and IDOV (identify, design, optimize, verify) are the most common acronyms used in DFSS (others include DCOV [define, characterize, optimize, verify], ICOV [identify, characterize, optimize, validate], DMEDI [define, measure, explore, develop, implement], IDDOV [identify, define, develop, optimize, verify], and GD[1] [good design, good discussion, good dissection]). These relate to DMAIC and help close the loop on improving the end product/process during the up-front design for Six Sigma phase. When the most common tools are used in the various phases, it is commonly stated that doing IDOV feeds the MAIC of DMAIC. The challenge is that we should be using the various Six Sigma tools on designs for products before they become a reality. As in many Six Sigma applications, scoping projects for DFSS (no matter which acronym you use) can be a challenge. Some issues to keep in mind include:

- Too small a scope—capture enough control factors to achieve robustness.
- Vague scope—no reference to a subsystem.
- Use of separate projects for each symptom.
- Too much time spent on rating systems—why wouldn't we be more robust if we could be?
- DFSS Methodology: Use robust, make robust, keep robust.

One of the central focuses that should be included in a DFSS project is to be very clear about what can happen to your product in the customer's hands. Things that you cannot control in the manufacturing process or how customers use your product are referred to as *noise*. You must allow for a noise strategy to improve a process. If there is a possible way for a customer to misuse your product, the probability is that they will. The root cause failure of DFSS is typically related to the team using too limited control factors (around the noise in the systems). Parts tend to be already designed before teams look for continual improvement opportunities.

Benefits of using DFSS in your organization should include such things as:

- Increased customer satisfaction—measured on the Kano model—see Chapter 5 for more information
- Reduced variation
- Improved robust design
- Decreased warranty costs
- Improved reliability, durability
- Increased market share
- Increased revenue, earnings growth
- Increased production—less production downtime due to defects

Following is a more detailed explanation of the two main DFSS processes in common use today.

IDOV

Woodford[2] refers to IDOV as a four-phase process that consists of *identify*, *design*, *optimize*, and *verify.* These four phases parallel the four phases of the traditional Six Sigma improvement methodology, MAIC—*measure*, *analyze*, *improve*, and *control.* The similarities can be seen below.

Identify Phase. The *identify* phase tasks link the design to the voice of the customer:

- Identify customer and product requirements
- Establish the business case
- Identify technical requirements, critical to quality (CTQ) variables, and specification limits
- Roles and responsibilities
- Milestones

Design Phase. The *design* phase tasks emphasize CTQ variables and attributes:

- Formulate concept design
- Identify potential risks using failure mode and effects analysis (FMEA)
- For each technical requirement, identify design parameters
- Plan procurement, raw materials, manufacturing, and integration
- Use DOE (design of experiments) and other analysis tools to determine CTQs and their influence on the technical requirements (transfer functions)

Optimize Phase. The *optimize* phase develops detailed design elements to predict performance and optimize design:

- Assess process capabilities to achieve critical design parameters and meet CTQ limits
- Optimize design to minimize sensitivity of CTQs to process parameters
- Design for robust performance and reliability
- Error-proofing
- Establish statistical tolerancing
- Optimize cost through reduced process variation

Validate Phase. The *validate* phase consists of testing and validating the design and recording information for design improvements:

- Prototype test and validation
- Assess performance, failure modes, reliability, and risks
- Design iteration
- Final phase review

DMADV

Breyfogle[3] refers to the approach known as DMADV (define, measure, analyze, design, verify), which he says "is appropriate, instead of the DMAIC approach, when a product or process is not in existence and one needs to be developed. Or the current product/process exists and has been optimized but still doesn't meet customer and/or business needs."

Historically, the redesign process has been found to be a common source of waste that can be reduced by enhancing the original design process. Design for Six Sigma is the process of designing with a particular attribute in mind:

1. Define. Before beginning a design initiative, the Six Sigma team needs to evaluate and prioritize the primary design objectives for the organization. By targeting the primary priorities, the design efforts will have the most significant impact possible on achieving Six Sigma targets.

2. Measure. This requires a combination of technical and competitive product management analysis, specifying the design criteria most valued by the industry and customer. In addition, there are expectations imposed by regulators, partners, and other stakeholders.

3. Analyze. The statistical and investigative approaches used for Six Sigma can identify design priorities with significance and confidence.

4. Design. Having obtained a clear direction for design objectives, it is incumbent on the Six Sigma team to collaborate with designers to ensure that the final design outputs include the desired attributes. If these are treated as requirements or specifications, the fulfillment of Six Sigma design objectives will be incorporated into the development and testing activities and embedded into the overall solution. Without this approach, the Six Sigma design objectives will have to be an additional layer, which is potentially expensive and wasteful.

Design for Cost (also known as Design to Cost). In most markets, cost has become a major consideration in the design process. This requires a constant search for alternative processes, materials, and methods. People with cost accounting and purchasing backgrounds can assist the design team in this quest.

Design for Manufacturing/Design for Producibility/Design for Assembly. Many companies have found that minor design changes can make the product easier and less costly to produce. Tolerance design can result in savings in machining processes, tooling, and gauging. Designers should be familiar with existing manufacturing equipment and processes and strive to design products that don't require additional capability. Some manufacturers have found that drastic reductions in the number of parts in a product is an effective way to reduce manufacturing costs. As a general rule, the earlier that manufacturing personnel are involved in the design process, the more producible the design.

Design for Test (also known as Design for Testability). In products where in-process testing is critical, designers must make provision for performing tests earlier in the production cycle rather than relying entirely on functional tests of a finished assembly or subassembly.

Design for Maintainability. The ability to perform routine maintenance must be considered in the design process. Products that require long downtimes for diagnosis and repair can cause the user to miss deadlines and alienate customers. Maintainability includes modularity, decoupling, and component standardization.

Design for Robustness. Adequate time must be allowed during the design process to conduct life cycle tests of all parts, subassemblies, and assemblies. Suppliers of purchased parts should be required to document the mean time to failure (MTTF) or mean time between failures (MTBF) for all products they supply. MTTF is used for nonrepairable items and MTBF is used for repairable items. A basic relationship in this area is that between failure rate λ and MTTF or MTBF:

$$\text{MTTF} = 1/\lambda \text{ or MTBF} = 1/\lambda \text{ and, of course,}$$
$$\lambda = 1/\text{MTTF or } \lambda = 1/\text{MTBF}$$

Design for Usability. The quality of a product is determined by *validation*, where it is applied for its prescribed purpose by its intended users in its specified environment. The ability of a user to work comfortably with the product, system, or service to obtain value can be measured and improved.

Design for Extended Functionality. Many products initially designed and intended for a single purpose can have their features applied to extended functionality beyond the initial vision of the designers. Computer software applications are good examples of products that were initially developed for quick mathematical calculation and numerical tracking, but are now preferred tools for graphic design, word processing, and database management.

Design for Efficiency. The product or system must be designed in a way that consumes minimal resources, both to make the product and to use the product or service. This is correlated with design for cost, except the criteria for evaluation are time, resources, and consumption of critical components. Efficiency will have positive effects on long-term cost and reliability.

Design for Performance. Performance refers to the achievement of aggressive benchmarks or breakthroughs on a consistent basis. Terms like "cutting edge" or "latest and greatest" reflect the constant challenge of exceeding once unachievable levels of delivery. Historical examples include the design of aircraft faster than the speed of sound, and the continuous increase in processing power of microchips.

Design for Security. Security is becoming a bigger threat as maladies like computer viruses, identity theft, and product misuse increase in scope and complexity. Security will preserve product integrity and protect the intellectual property and privacy of users and designers.

Design for Scalability. Products or systems deployed for use in a growth market should anticipate expansion or rapid adoption. Without this attribute, quality will be compromised when the product surpasses the threshold of users or scope. An example is the auction website that suddenly has a blank screen during peak periods because it cannot handle the load of 100,000 concurrent users at month-end.

Design for Agility. Many organizations compete on their ability to deliver customized solutions within a short time. This requires a nimble approach to rapid development, a robust architecture or structural foundation, and a ready array of components or vendors who can augment the core product with unique touches.

Table 3.1 Design objectives and outputs traceability matrix.

Design objective	Design output	Status
Extended functionality	Business user can apply software to their operations	Achieved functionality
Maintainability	Modular approach with minimal coupling	Replacement of modules results in quicker diagnosis and maintenance
Efficiency	Point-of-sale transaction system allows sale to be completed within five minutes	Design supports the application of the product to make customers more efficient
Security	Password encryption for user access	Security achieved to prevent unauthorized product use
Compliance to Kyoto standards for emissions	Product did not pass mandated emissions standards	Redesign is required for marketability

An example is a hot tub manufacturer who incorporates the basic hot tub into the style and design of a building or landscape to create a seamless effect.

Design for Compliance. Designers have regulations imposed on them that must be fulfilled in order for the product to be marketed. Compliance requirements can range from achieving specific product performance capabilities to demonstrating that suitable design processes were followed and recorded. If the DFSS initiative is operating in a highly regulated environment, cost-benefit can be derived by the penalties/fines and opportunity costs of noncompliance. An example is designing a process that requires configuration management updates every time the product is changed, to ensure proper and accurate documentation. Example: If the U.S. auto industry does not meet the California emission standards, then cars/trucks cannot be sold there.

5. Verify. ISO 9000:2015 clause 3.8.12 defines *verification* as the "confirmation, through the provision of objective evidence, that specified requirements have been fulfilled." This can be completed by the Green Belt or others in the company during the APQP or Toll Gate processes (both described later in this handbook) or independently by outside third-party companies. Verification should be completed prior to the full release of a product or service to the full production phase of making/delivering something.

ISO 9000:2015 clause 3.8.13 defines *validation* as the "confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled." This can be accomplished through any number of internal audits or the use of the Rice and Munro Evaluation Model (described in Appendix O) for validation of learning outcomes.

BASIC FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

> Use FMEA to evaluate a process or product and determine what might cause it to fail and the effects that failure could have. Identify and use scale criteria, calculate the risk priority number (RPN), and analyze the results. (Analyze)
>
> **Body of Knowledge I.C.2**

The essence of a *failure mode and effects analysis* (FMEA) is the study of risk, and it has grown into multidisciplinary fields of study with many resulting risk methodologies. Risk is about the uncertainty of an event. Another way to say this is that risk is about what might happen, good or bad, that will influence/affect what happens at work, with the product/service, how a customer might use or misuse your product/service, or any other issue that management might identify as a concern.

Risk can also be defined in terms of three aspects: impact (severity), probability (occurrence), and event (detection). *The Risk Management Memory Jogger*[4] lays out a Risk Road Map for ISO 31000:2018 of:

- Plan risk management
- Risk identification tools
- Analyze and evaluate risk
- Plan risk response
- Monitor and control risk

The concepts of what we call failure mode and effects analysis have been around a long time under various names (originally called failure mode, effects, and criticality analysis [FMECA]) and follow the Risk Road Map concepts above. In the past, inventors and product developers thought about possible ways that a product could fail during extreme conditions, handling, and usage. They started to provide countermeasures in the design and manufacturing process to prevent these failure modes. FMEA thus started to evolve informally. A brief history of standards and processes includes (see Appendix N for additional listings):

- The U.S. Military first issues what we now know as FMEA on November 9, 1949—Military P-1629: *Procedures for Performing a Failure Mode, Effects and Criticality Analysis*. This led into the MIL-STD 1629 series of documents.
- NASA's Apollo space program uses RA-006-013-1A: *Procedure for Failure Mode, Effects, and Criticality Analysis (FMECA)*, August 1966.
- Enterprise risk management (ERM)—in the early 1970s Gustav Hamilton of Sweden's Statsfoetag proposes the "risk management circle."

- Ford Motor Company starts using FMEA in the late 1970s after the Pinto issue.
- The NASA Challenger disaster on January 28, 1986, exposes a Morton-Thiokol O-ring FMEA in the resulting legal litigation.
- The Committee of Sponsoring Organizations (COSO) is organized in 1985. The full name is Committee of Sponsoring Organizations of the Treadway Commission, and their focus is on the financial aspects of risk management and fraud prevention.
- The Automotive Industry Action Group (AIAG) releases the first Big Three PFMEA in February 1993. (History: February 1993, February 1995, July 2001, fourth edition 2008.)
- SAE International releases SAE J-1739: *Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes (Process FMEA)* 2009-01-15. (History: 1994-07-01, 2000-06-01, 2002-08-02, 2009-01-15.)
- ASQ publishes the first edition of D. H. Stamatis, *Failure Mode and Effect Analysis: FMEA from Theory to Execution* in 1995, second edition June 2003.
- AIAG releases *FMEA for Tooling & Equipment (Machinery FMEA)* November 1, 2001—second edition February 2012
- International Organization for Standardization (ISO) releases ISO 31000: 2018 *Risk management—Principles and guidelines*.
- IATF released a new FMEA Handbook by AIAG & VDA in June 2019.

ISO is also updating the ISO 9001 quality management system (QMS) in 2015 to include what they call "risk-based thinking." ISO 9001 0.5 states in part, "This International Standard makes risk-based thinking more explicit and incorporates it in requirements for the establishment, implementation, maintenance and continual improvement of the quality management system. Organizations can choose to develop a more extensive risk-based approach than is required by this International Standard, and ISO 31000 provides guidelines on formal risk management which can be appropriate in certain organizational contexts."

There are many resources for FMEA and related methodologies. One starting point could be the FMEA Info Centre (www.fmeainfocentre.com). Terms you might consider searching include risk, risk assessment, risk management, enterprise risk management, FMEA, COSO, and many others.

Why Do FMEAs?

The concept of using a risk matrix (see Figure 3.1) to analyze a given situation is not new in today's thinking in many organizations. The automotive industry (through AIAG and SAE International) has been in the forefront of developing the FMEA methodology. The fundamental reason for using an FMEA is to predict the highest likelihood of things that could go wrong (at the concept, design,

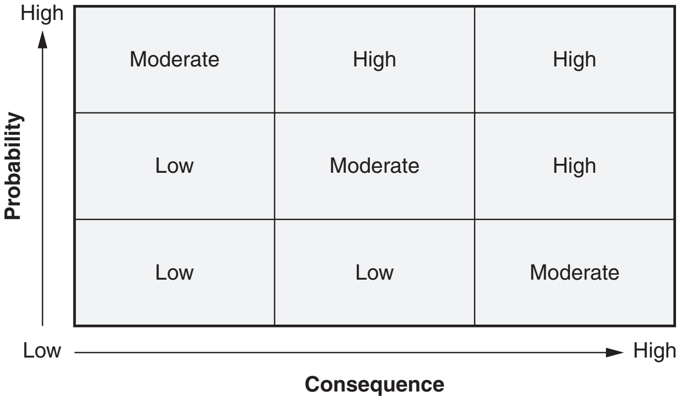


Figure 3.1 Simple risk matrix.

process, machinery, or system level). The old adage of "a stich in time saves nine" very much applies here. If we think through the upcoming process and formally write it out on paper (or in a software system), it gives us a much better chance to predict and prevent occurrences or situations that may cause our organization an unpleasant issue.

The AIAG described FMEA as a systematic group of activities intended to:[5]

- Recognize and evaluate the potential failure of a product/process and the effects of that failure
- Identify actions that could eliminate or reduce the chance of the potential failure occurring
- Document the entire process

Note: The AIAG and VDA FMEA Handbook was meant to replace the fourth edition AIAG FMEA Manual; however, at the time of printing this handbook, the new FMEA reference has not received full endorsement within the automotive community.

The purpose of automotive design FMEA (DFMEA) and process FMEA (PFMEA) is to understand the opportunities for failure and the impact of risks in a product or process design, prioritize the risks, and take actions to eliminate or reduce the impact of these risks. Successful product/process development requires anticipating failure modes and taking actions to eliminate or reduce failure during deployment and life cycle. FMEA is not a one-time event; the product/process design team needs to periodically review and update the failure modes. During the early stages of product/process development, the team identifies the risks based on existing data from similar processes, knowledge, and experience. As the product/process is deployed, new, unforeseen risks and failures may show up. Hence, reviewing the FMEA on a continual basis ensures sustainable success. Carlson[6] includes a number of FMEA checklists in his book that can be found at www.effectivefmeas.com.

FMEA needs to be documented and revision-controlled and should be part of the existing quality management system (QMS). In a well-designed QMS, FMEA is linked to quality function deployment in the design and process “houses of quality,” and linked to control plans in the production house of quality. Part of this document control process is needed as the FMEA is considered to be a living document—that is, it should be updated as needed and the revisions controlled to track changes over time.

Another key aspect to the use of the FMEA risk management concept is that FMEA is not just confined to manufacturing applications. FMEA has been successfully used in service/transactional processes, software development, the medical field, and so on.

Once the FMEA is completed, some of the benefits/uses that you should see include:

- Assesses effect on all customers (internal and external)
- Aids in evaluating requirements and alternatives
- Identifies potential design, manufacturing, or assembly cause issues and needs to focus on controls for reducing occurrence and/or increasing detection
- Develops a prioritized list for actions (ongoing as a living document)
- Helps validate the intended design, manufacturing, or assembly process
- Documents the results of the design, manufacturing, or assembly process
- Identifies confirmed special characteristics requiring special controls

Although in principle FMEA is conducted to address the potential failures in product design and process design, FMEA is identified separately as *design FMEA* (DFMEA) and *process FMEA* (PFMEA). (There are also the concept FMEA, machinery FMEA, and system FMEA, which are beyond the scope of this BoK.)

FMEA Forms/Tables

The typical FMEA format is a simple matrix that can be easily duplicated in a simple spreadsheet software program. Specialized software programs are also available to help create the form as your team works through the process. Depending on the industry that you work in, there may be specific formats that are required, so checking with your organization’s quality manager or quality engineer might be advisable if you are unfamiliar with this tool. Some common column headers used today include those for design FMEA (see Figure 3.2) and process FMEA (see Figure 3.3).

Steps in Performing FMEA

A team approach has proven to be the most effective method for conducting an FMEA, so it is discussed here. Assemble a cross-functional team with diverse

Potential
Failure Mode and Effects Analysis
(Design FMEA)

____ System
____ Subsystem
____ Component ____________________
Model year(s)/Vehicle(s) ________________
Core team ____

Design responsibility ____________________________
Key date ______________________________________

FMEA number ___________
Page # _______ of _______
Prepared by _________________________
FMEA date (orig.) ________ (rev.) _________

Item / Function	**Potential failure mode**	**Potential effect(s) of failure**	**S**	**Class**	**Potential cause(s)/ mechanism(s) of failure**	**O**	**Current design controls** • **Prevention** • **Detection**	**D**	**RPN**	**Recommended action(s)**	**Responsibility and target completion date**	**Action results**				
												Action taken	**S**	**O**	**D**	**RPN**

or

Item / Function	**Potential failure mode**	**Potential effect(s) of failure**	**S**	**Class**	**Potential cause(s)/ mechanism(s) of failure**	**O**	**Current design controls Prevention**	**Current design controls Detection**	**D**	**RPN**	**Recommended action(s)**	**Responsibility and target completion date**	**Action results**				
													Action taken	**S**	**O**	**D**	**RPN**

Figure 3.2 Sample DFMEA headers.

Potential
Failure Mode and Effects Analysis
(Process FMEA)

FMEA number ___________
Page # _______ of _______
From ______________________________
Process responsibility ___________________________
Prepared by _________________________
Model year(s)/Vehicle(s) _______________
Key date _____________________________________
FMEA date (orig.) _______ (rev.) ________
Core team ____

Item / Function	Potential failure mode	Potential effect(s) of failure	S	Class	Potential cause(s)/ mechanism(s) of failure	O	Current design controls • Prevention • Detection	D	RPN	Recommended action(s)	Responsibility and target completion date	Action results				
												Action taken	S	O	D	RPN

or

Item / Function	Potential failure mode	Potential effect(s) of failure	S	Class	Potential cause(s)/ mechanism(s) of failure	O	Current design controls Prevention	Current design controls Detection	D	RPN	Recommended action(s)	Responsibility and target completion date	Action results				
													Action taken	S	O	D	RPN

Figure 3.3 Sample PFMEA headers.

knowledge about the process, product, or service, and customer needs. Functions often included are design, manufacturing, quality, testing, reliability, maintenance, purchasing (and suppliers), shop floor operators, sales, marketing (and customers), and customer service. It is important to have process experts present in design FMEA and design experts in process FMEA. For effective interaction, the team is typically five to seven people. If additional experts are needed to provide inputs on safety, regulatory, or legal issues, they are included in the team as subject matter experts.

Identify the scope of the FMEA. Is it for concept, system, design, process, or service (yet another FMEA type)? What are the boundaries? How detailed should we be? What will be the overall focus of the effort your team is about to work on? A basic flow of the FMEA process is shown in Figure 3.4 and is called the *FMEA flowchart*. This figure shows a basic three-step process for thinking through the various aspects that are needed when working on an FMEA. Figure 3.5 shows how this flowchart fits on a typical FMEA form. As your team works through the various columns of the form, a key item to remember is that there are no absolutes, and if disagreement arises, consider taking a middle ground for the time being (maybe listing a note for further study later on) so that the team does not get bogged down in the overall process. Table 3.2 gives more detail for performing an FMEA.

Severity, Occurrence, and Detection Tables

As the potential failure modes are identified by the cross-functional team, a determination of score needs to be developed for each of the three primary categories of *severity*, *occurrence*, and *detection*. Just as each word indicates, you will need

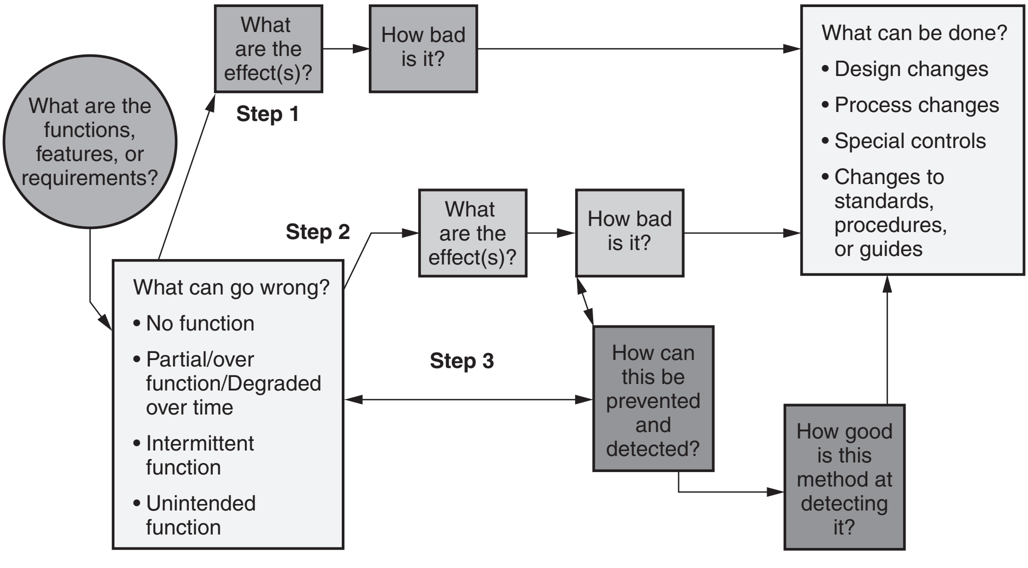


Figure 3.4 FMEA flowchart.

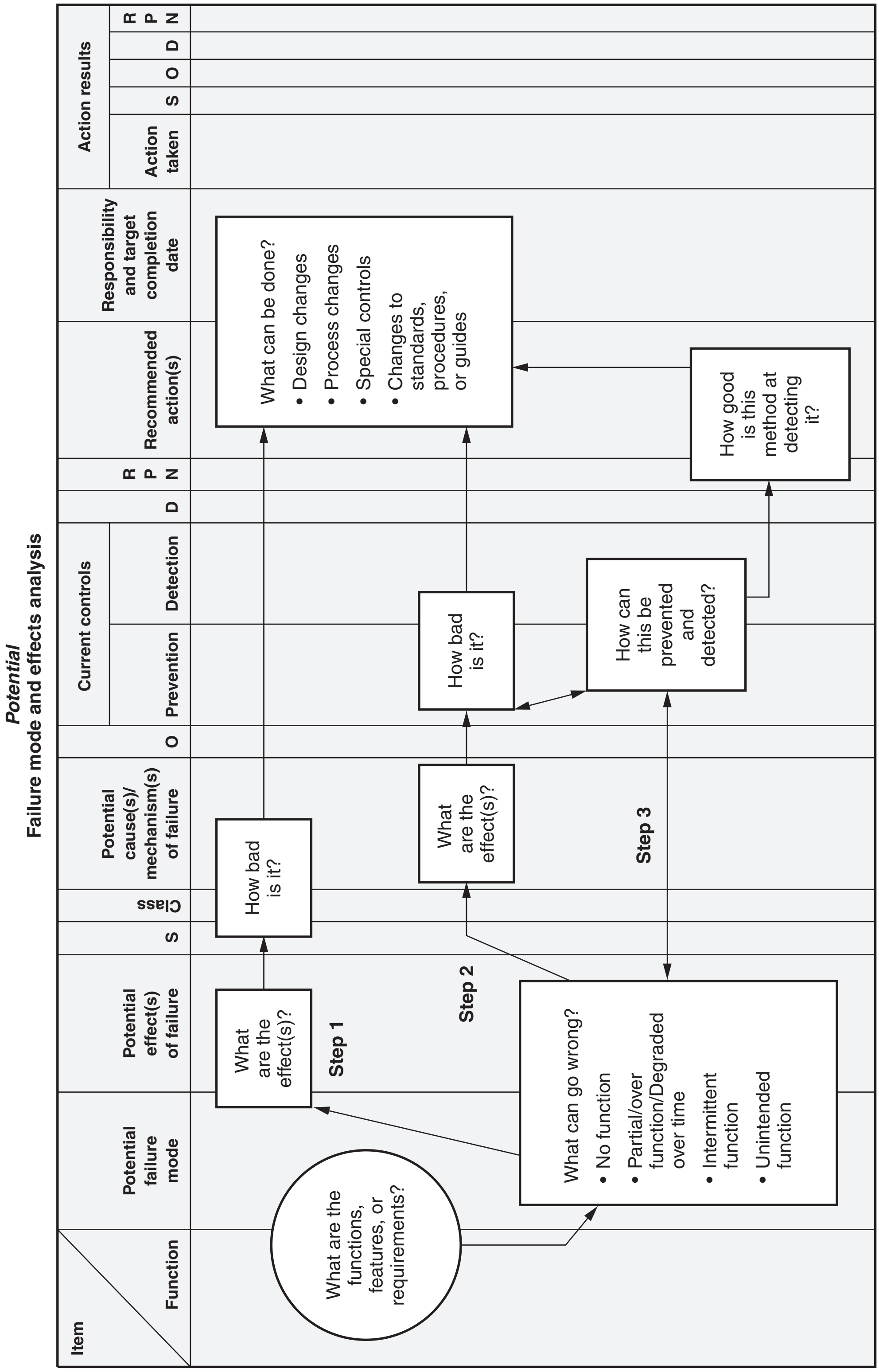


Figure 3.5 FMEA flowchart in line with common FMEA form.

Table 3.2 Steps in performing a design or process FMEA.

	Steps	Design FMEA	Process FMEA
1	Review the design/process	Use schematic diagram and functional block diagram to identify each of the main components of the design and determine the function or functions of those components and interfaces between them. Make sure you are studying all components defined in the scope of the DFMEA. Some components may have more than one function.	Use flowcharts to identify the scope and to make sure every team member understands it in detail. It is also recommended that the team perform a walk-through of the process and understand the process steps firsthand.
2	Brainstorm potential failure modes	A potential failure mode represents any manner in which the product component could fail to perform its intended function or functions.	A potential failure mode represents any manner in which the process step could fail to perform its intended function or functions.
3	List potential effects of failure	The potential effect at interim (local) and end effects are both identified. The effect is the ability of the component to perform its intended function due to the failure mode.	The potential effect at interim (local) and end effects are both identified. The effect is the impact on the process outcome and product quality due to the failure mode.
4	Assign severity rating (S)	*Severity* rating corresponds to each effect the failure mode can cause. Typically, the scale is 1 to 10. Higher severity is rated at the high end, lower severity at the low end of the scale.	
5	List potential causes	For every failure mode, list possible cause(s). Use team tools like brainstorming, cause-and-effect charts, NGT, multivoting, and so on. Where applicable, use a pilot experiment, past data, expert knowledge.	
6	Assign occurrence rating (O)	*Occurrence rating* corresponds to the likelihood or frequency at which the cause can occur. Typically, the scale is 1 to 10. Higher occurrence is rated at the high end, lower occurrence at the low end of the scale.	
7	Current controls	For each cause, current process controls are identified. Controls can be of different types. They may just detect the failure or prevent the failure from happening. The controls range from work instructions to AQL sampling, SPC, alarms, mistake-proofing fixture, and so on.	
8	Assign detection rating (D)	*Detection rating* corresponds to the ability to detect the occurrence of the failure mode. Typically, the scale is 1 to 10. Higher detectability is rated at the low end, lower detectability at the high end of the scale.	
9	Calculate RPN	Product of severity (S), occurrence (O), and detection (D). S × O × D= Risk priority number (RPN). Severity × Occurrence = Criticality is also important in some industries.	

Continued

Table 3.2 Steps in performing a design or process FMEA. *(Continued)*

	Steps	Design FMEA	Process FMEA
10	Develop action plan	Action plan may contain tasks to improve the current controls or reduce the frequency of the occurrence of the cause. In order to reduce the severity, the team may have to think of redesigning the product or process. Assign a realistic completion date and responsibility for tasks.	
11	Take action	This is a step where many FMEAs fall apart due to lack of management support, conflicting priorities, lack of resources, and lack of team leadership. The actions have to be implemented and results should be validated. Building a prototype and testing the action and piloting the process in small scale before mass producing are recommended.	
12	Recalculate the RPN	Bring the team back and objectively recalculate the RPN. Use objective evidence like customer feedback, reliability tests, warranty return rate, yield tracking, and so on, to reassess the score.	
13	Periodically review and update new risks	Carefully evaluate customer feedback, warranty analysis, internal nonconformance reports, ongoing reliability test reports, and so on, to explore new risks and update the FMEA. Keep the FMEA as a living document.	

to evaluate each failure mode, based on the scoring table you are using (sample tables can be found in the J-1739 or PFMEA-4 standards). Many tables used in manufacturing organizations run from 1–10, while some tables can also be scored 1–5. One key here is to have tables that meet the needs and requirements of your specific industry and organization. This could require either reliability engineers or quality engineers working with warranty data and other information from within your organization to create company-specific tables for your needs.

The process involves the team selecting the number from the identified table that most closely indicates the team's estimate. This could include an issue that will cause harm to workers or customers if used improperly, which should yield a severity of 9 or 10 depending on how serious the injury might be.

For occurrence, you generally look at past times that the issue may have occurred, and greater frequency yields higher numbers. Thus, if something happens on a daily basis, it could have a number between 8 and 10. In detection, the numbering usually works in reverse of severity in that the least likelihood of actually detecting something will yield the highest numbers. So, if an operator can obviously see the error every time it might happen, then the score would be a low number such as 1 or 2.

Sample potential failure mode tables are shown for severity (Table 3.3), occurrence (Table 3.4), and detection (Table 3.5).

Table 3.3 Possible severity evaluation criteria.

Effect	Criterion: Severity of effect	Ranking
Hazardous without warning	Very high severity ranking when a potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning.	10
Hazardous with warning	Very high severity ranking when a potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation with warning.	9
Very high	Vehicle/item inoperable (loss of primary function).	8
Low	Vehicle/item operable but comfort/convenience item(s) operable at a reduced level of performance. Customer somewhat dissatisfied.	5
Minor	Fit and finish/squeak and rattle item does not conform. Defect noticed by 50% of customers.	3
None	No discernible effect.	1

Table 3.4 Possible occurrence evaluation criteria.

Probability of failure	Possible failure rates	Ranking
Very high: Persistent failure	≥ 100 per thousand vehicles/items	10
	50 per thousand vehicles/items	9
Moderate: Occasional failures	5 per thousand vehicles/items	6
	2 per thousand vehicles/items	5
	1 per thousand vehicles/items	4
Remote: Failure unlikely	≤ 0.01 per thousand vehicles/items	1

Table 3.5 Possible detection evaluation criteria.

Detection	Criterion: Likelihood of detection by design control	Ranking
Absolute uncertainty	Design control will not and/or cannot detect a potential cause/mechanism . . . or there is no design control	10
Moderately high	Moderately high chance the design control will detect potential cause/mechanism and . . .	4
Almost certain	Design control will almost certainly detect a potential cause/mechanism . . .	1

Risk Priority Number

Once the team has identified the three numbers for severity, occurrence, and detection (S-O-D) for a given failure mode, then the three numbers are multiplied together to create what is called the *risk priority number* (RPN) (see Figure 3.6). This is the number that is the starting point for analyzing what failure modes should be addressed first (you will need to review the rules for your industry as to how to apply the RPN, as some groups want the severity number to take higher priority over the overall RPN). Once the entire FMEA is completed, a Pareto diagram can be completed of the various RPN numbers to see which failure modes have the biggest potential for issues in your organization.

Many FMEA forms have a far right-hand column that should be used by the cross-functional team to show when actions have been taken on a particular failure mode to reduce the overall RPN as part of the due diligence of the team to prevent issues before they might occur. Thus, a road map of ongoing work for continual improvement projects can be set up; the FMEA should be considered a living document as the team continually works to prevent issues in the design/process using the FMEA as their guide. Thus, the team should meet periodically to update information in the FMEA and to see where additional efforts might be targeted to improve the overall process.

Do's

- Always provide FMEA training to team members before assignment to an FMEA team.
- Always use the team approach.
- Ask for subject matter expertise if required.
- Talk to your customer about how they intend to use the product.
- Take time as a team to standardize the scales (the scale to be used should be based on the nature of business or the organization versus some generic table that may not apply to your situation). This helps when comparing the overall risks between FMEAs and helps set up a cutoff score.
- Brainstorm all possible failure modes, even if they only happen occasionally.

S	**×**	**O**	**×**	**D**	**=**	**RPN**
2	×	8	×	10	=	160
10	×	5	×	2	=	100
8	×	2	×	9	=	144

Figure 3.6 Example of RPN calculations.

- When two risks have the same overall score, the risk with the higher severity rating is escalated.
- Complete the action and reassess the risks as a team.
- Update the FMEA with any new learned risks.

Don'ts

- Try not to copy the S-O-D scales from another industry or from a different organization. The description of the scale levels and impact may be different.
- Try not to force-fit into a 1 to 10 scale. If there are not many levels of severity, occurrences, or detection in your industry, try a 1 to 5 scale.
- Discourage creating customized scales within the organization unless absolutely essential.
- Don't fight over ratings of small difference, such as between 4 and 5 or 6 and 7. Analyze the impact thoroughly if the team is divided by two or three rating points, for example, 4 and 7.
- Don't get hung up on a numbers game; the objective is to create a reduced-risk product and/or service.
- Don't perform FMEA just to comply with procedures or standards. FMEA is a business risk management tool. It has to be used with commitment to make it work.

Successful FMEA implementation requires leadership and management commitment. Few tools can test the patience of team members as finishing an FMEA; tackle multiple process steps for the product as a team in several meetings. In these cases, split the process into major process blocks and perform FMEA by block. Maintain a good FMEA database. This will significantly reduce the time spent on successive FMEAs.

Once the initial RPN scores are tabulated, the team may decide on a cutoff score. For most organizations, the cutoff score is standardized. The cutoff score of one organization may not be directly applicable to another. Too low a cutoff score can result in spending lots of resources to eliminate or reduce several risks. Too high a cutoff can result in not addressing important risks. Management needs to review the data and agree on a score.

Figures 3.7 through 3.11 show various FMEA implementation tools and examples.

Before taking action					After taking action				
Risk ID	S	O	D	Initial RPN	Risk ID	S	O	D	Recalc RPN
Risk 7	5	8	7	280	Risk 7	5	5	3	75
Risk 1	8	8	4	256	Risk 1	8	4	3	96
Risk 3	5	5	7	175	Risk 3	5	4	4	80
Risk 9	7	5	4	140	Risk 9	7	3	4	84
Risk 5	8	4	4	128	Risk 5	8	3	3	72
Risk 2	7	4	3	84	Risk 2	7	4	3	84
Risk 4	5	5	3	75	Risk 4	5	5	3	75
Risk 6	3	7	2	42	Risk 6	3	7	2	42
Risk 8	5	3	2	30	Risk 8	5	3	2	30
Risk 10	3	3	3	27	Risk 10	3	3	3	27

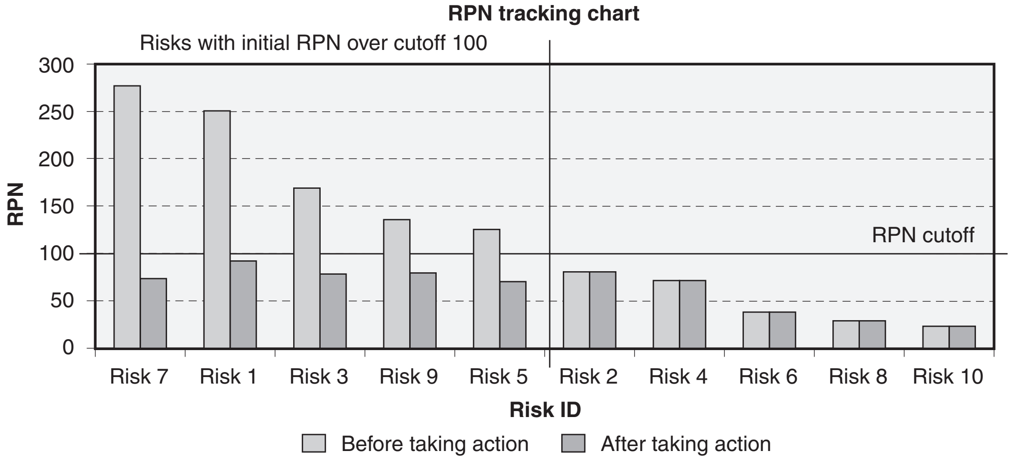


Figure 3.7 Example FMEA reporting and RPN chart.

Note: FMEA is a powerful tool but requires in-depth knowledge to successfully execute. It is recommended that guidance be sought from others who have performed an FMEA prior to or during the application of an FMEA to an improvement project.

Please see the Glossary for some of the fundamental terms used in FMEA such as *failure mode, cause, effect, failure mechanism, severity, occurrence, detection, risk priority number,* and so on.

Note: The automotive industry has developed a new FMEA handbook that does change the concept of the RPN to a risk rating. The concepts and usage of the FMEA remain unchanged in this handbook.

Risk ID		Jan 07	Feb 07	Mar 07	Apr 07	May 07	Jun 07
Risk 7	Planned	▨	▨	▨			
	Actual						
Risk 1	Planned		▨	▨	▨	▨	▨
	Actual						
Risk 3	Planned	▨	▨				
	Actual						
Risk 9	Planned		▨	▨			
	Actual						
Risk 5	Planned			▨	▨	▨	
	Actual						

Figure 3.8 A typical risk action plan Gantt chart.

XYZ Corporation

Management Review Report—FMEA Implementation Progress

No. of FMEA risks over cutoff 100 = 245

Total no. of FMEA risks identified = 550

No. of risks to be reduced below cutoff by end of quarter* = 60

*Organizations review their performance by end of Q1, Q2, Q3, and Q4.

Figure 3.9 A typical top-level management review report for FMEA progress.

Function	Potential failure mode	Potential effect(s) of failure	S	Potential cause(s) of failure	O	Current process controls	D	RPN	CRIT	Recommended action(s)	Responsibility and target completion date	Action results					
												Action taken	S	O	D	RPN	CRIT
Dispense amount of cash requested by customer	Does not dispense cash	Customer very dissatisfied Incorrect entry to demand deposit system Discrepancy in cash balancing	8	Out of cash	5	Internal low-cash alert	5	200	40								
				Machine jams	3	Internal jam alert	10	240	24								
				Power failure during transaction	2	None	10	160	16								
	Dispenses too much cash	Bank loses money Discrepancy in cash balancing	6	Bills stuck together	2	Loading procedure (riffle ends of stack)	7	84	12								
				Denominations in wrong trays	3	Two-person visual verification	4	72	18								
	Takes too long to dispense cash	Customer somewhat annoyed	3	Heavy computer network traffic	7	None	10	210	21								
				Power interruption during transaction	2	None	10	60	6								

Figure 3.10 An example of a partially filled-in FMEA.

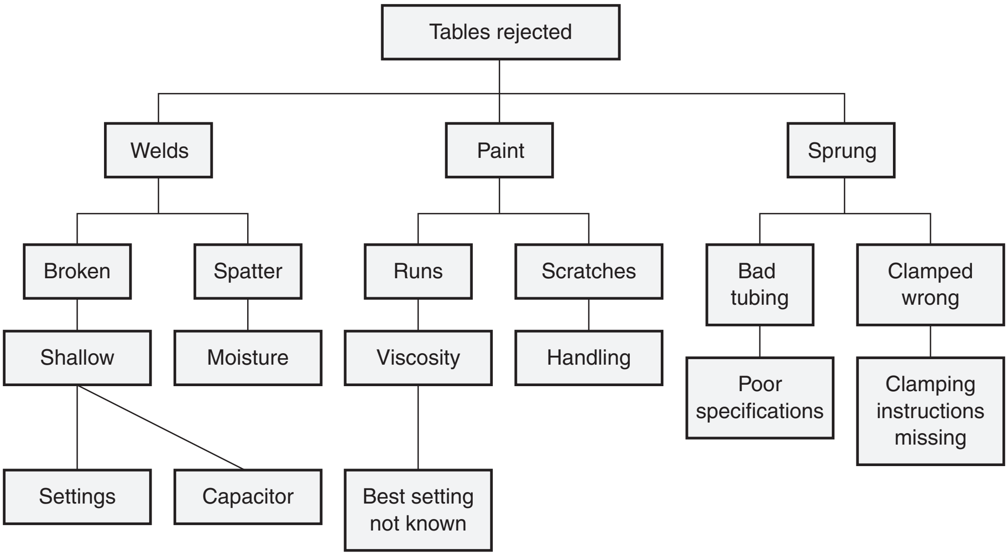


Figure 3.11 This example of a tree diagram is a fault tree (used to study defects and failures).

DESIGN FMEA AND PROCESS FMEA

> Define and distinguish between these two uses of FMEA. (Apply)
>
> **Body of Knowledge I.C.3**

There are any number of uses for the FMEA methodology. Figure 3.12 shows how several of these manufacturing methods (concept, design, process, machinery, and system) can fit and work together. We could also add "management" to this figure, which is found in the ERM systems discussed earlier. All of this together makes up what is referred to in the ISO management system standard series (9001, 14001, 22301, 45001, and 50001) as *risk management* and will be required of your organization if it is to be registered to one of the standards. Note: the ISO now has over 50 management system standards.

For distinguishing between the design and process FMEA, a key item to remember is, what is your end goal in creating the FMEA document? Sequentially, you should consider creating a concept FMEA first, followed by a design FMEA, and then a process FMEA. Many times in a manufacturing setting there is no concept FMEA or design FMEA, so the engineer or manager must work with what they have to create the process FMEA without knowing all aspects of the design intent.

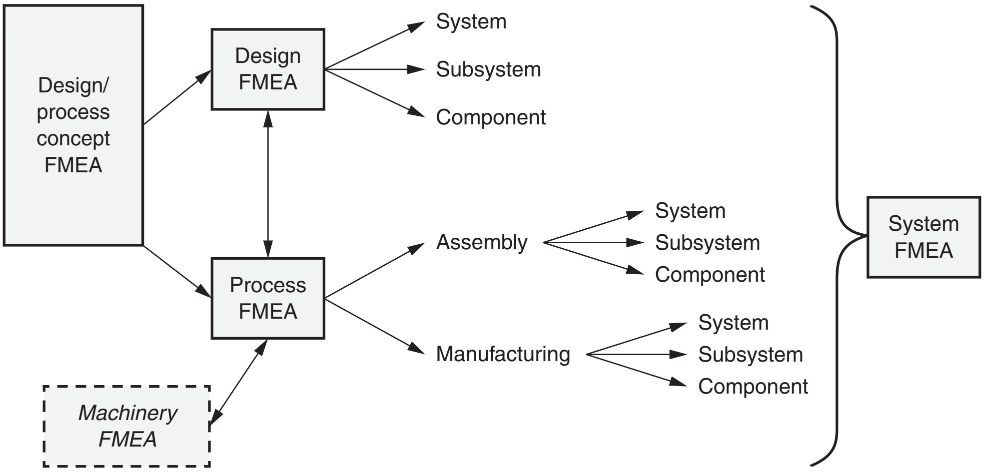


Figure 3.12 Common types of FMEA.

Design FMEA is about the product design and should be used by designers and process engineers to think through possible issues in creating the designs/drawings in certain ways versus other alternatives. If they design something in one particular way versus another, what ramifications could that characteristic have on the part, how it is made, or how it will be used by the customer? If we are designing toys for small children, are there any small components that could come loose and become choking hazards? If we design a tire jack that might slip when used by the vehicle owner with a flat tire, additional injury might be the end result.

As discussed earlier, working through the design FMEA during these early stages before tooling is cut and final processes have been established can save your organization vast amounts of time and money. Design FMEAs can be done at various levels, as seen in Figure 3.12, such as the system level, subsystem level, or component level.

Process FMEA is about the shop floor manufacturing process and should be done at the beginning of developing the manufacturing process layout for either manufacturing or assembly of parts or components. Here, too, we can view manufacturing or assembly at various levels: system level, subsystem level, or component level.

Differences between Design and Process FMEA

If you are reviewing an FMEA to understand the process more, you should first note what the header block says about which type of FMEA you're looking at. The header should clearly indicate the type of FMEA, such as design, process, or some other system-level document. The methods of analyzing and completing the forms are similar, as has been discussed. The difference between design and process FMEA will be in the application of the FMEA as used in your industry or organization.

The general forms used by both SAE J-1739 and AIAG PFMEA-2 are very similar except for the name in the header block and the spacing of some of the columns. Many people use an Excel spreadsheet to create their FMEA forms, and there are also many software packages available for working through the FMEA process.

Note: Most of the discussion around DFMEA and PFMEA was centered around a manufacturing organization and can equally apply to any service organization.

Part II

Define Phase

Chapter 4 Project Identification
Chapter 5 Voice of the Customer (VOC)
Chapter 6 Project Management Basics
Chapter 7 Management and Planning Tools
Chapter 8 Business Results for Projects
Chapter 9 Team Dynamics and Performance

Part II is an overview of the *define* process for Six Sigma systems. It covers approximately 20 of the 100 questions that will be asked on the ASQ CSSGB Exam.

Where are we? Or, what is the problem? Where do we want to be? How will we get there? How will we know when we are there?

These are critical questions that are asked and answered during the *define* phase. Without understanding these basic tenets, the activity (or project) to resolve the problem or improve performance can flounder aimlessly, wasting needed resources and frustrating personnel to the point of not supporting an improvement culture.

This section will provide:

1. An overview of the define phase that includes process flows and guidelines to help ensure that a project is on track. Here the difference between defining the "improvement project" and defining the "issue or problem" will be discussed. We will also discuss how these two items, "project" and "problem," differ, and how they are similar. Finally, the overview will close out with guidance on tailoring the define phase intensity to the specific activity to be worked, in other words, how to keep this simple.
2. A review of each area of the ASQ Certified Six Sigma Green Belt Body of Knowledge. The goal here is to provide information that can help you successfully pass a certification exam, but more importantly, to ensure that this handbook is a tool that helps you execute improvement projects. In this review, tools that can be used will be discussed at a high level, with more in-depth explanations provided later in the section.

3. A tools section to provide detailed information regarding applicable define phase tools—how they work and how and when to use them. This section also lists additional resources in different media (that is, in print or online). The purpose of listing these additional resources is to ensure a balanced view of the tools and to provide usable templates and resources to execute a Green Belt project.
4. A summary of the items discussed that highlights the most commonly used tools, key resources, critical factors to success, and general process flows for successful execution of a project.

OVERVIEW

The *define* phase of the DMAIC model serves two purposes: to define the project management process for the Green Belt improvement project and to define the problem or issue to be worked on by the Green Belt project team. This overview will outline these two focus areas by detailing basic processes and recommended items for each area, and annotating potential pitfalls to avoid.

As noted, when we execute the define phase, two primary deliverables are the project plan and detailed knowledge of the current state of the problem. The *project plan* outlines several aspects of the project to ensure that the Green Belt project team and key stakeholders understand what needs to be done, what resources (for example, people, financial, tools and equipment, infrastructure) are anticipated, and when things will be completed. The documentation associated with gaining knowledge of the problem and the current state of the process varies widely based on the problem or issue being worked on. The primary goal is to have sufficient detail on what is happening to cause the undesirable performance or nonconformance to keep the project focused through the remaining DMAIC phases.

An organization that has an improvement culture based on a proven methodology, such as DMAIC, will be able to consistently improve performance and eliminate problems. However, if the organization allows itself to become mired in bureaucracy, it could lose this edge and reduce the overall effectiveness and motivation to improve. One method to avoid this pitfall is to ensure that the improvement culture process (based on a methodology like DMAIC) allows for flexibility in the level of project detail and tool selection. For example, some projects may only need a short charter approved by a process owner, champion, Black Belt, or Master Black Belt. Yet others, especially larger projects, may require a more detailed plan, coordination with multiple process owners, intra-phase reviews, and so on.

Keep things simple, adjust based on the process, but stay true to the basic methodology—this should lead to a successful improvement program embraced across the entire organization. One caution: be aware not to focus on sub-area/process optimization to the detriment of the whole process or "system." As noted above, the first section will follow the outline of the ASQ Certified Six Sigma Green Belt Body of Knowledge. Although this makes the most sense for the handbook and as a certification resource, note that in many cases it is better to outline the project management aspects and get stakeholder buy-in prior to spending too many resources on defining the problem and fully understanding the current state of the problem or process.

Key Point: Ensure that the management and money are lined up before starting any project—and check in often.

Key Point: The more time you spend up front in good planning, the higher the probability of a successful project.

Part VII

Appendices

Appendix A ASQ Code of Ethics
Appendix B Six Sigma Green Belt Body of Knowledge Map 2014–2022
Appendix C ASQ Certified Six Sigma Green Belt (CSSGB) Body of Knowledge (2022)
Appendix D Control Limit Formulas
Appendix E Constants for Control Charts
Appendix F Areas under Standard Normal Curve
Appendix G *F* Distributions
Appendix H Binomial Distribution
Appendix I Chi-Square Distribution
Appendix J Exponential Distribution
Appendix K Poisson Distribution
Appendix L Values of the *t*-Distribution
Appendix M Acronym List
Appendix N Quality Profession Historically Speaking
Appendix O Rice & Munro Training Evaluation Model

Appendix A

ASQ Code of Ethics

INTRODUCTION

The purpose of the American Society for Quality (ASQ) Code of Ethics is to establish global standards of conduct and behavior for its members, certification holders, and anyone else who may represent or be perceived to represent ASQ. In addition to the code, all applicable ASQ policies and procedures should be followed. Violations to the Code of Ethics should be reported. Differences in work style or personalities should be first addressed directly with others before escalating to an ethics issue.

The ASQ Professional Ethics and Qualifications Committee, appointed annually by the ASQ Board of Directors, is responsible for interpreting this code and applying it to specific situations, which may or may not be specifically called out in the text. Disciplinary actions will be commensurate with the seriousness of the offense and may include permanent revocation of certifications and/or expulsion from the society.

FUNDAMENTAL PRINCIPLES

ASQ requires its representatives to be honest and transparent. Avoid conflicts of interest and plagiarism. Do not harm others. Treat them with respect, dignity, and fairness. Be professional and socially responsible. Advance the role and perception of the Quality professional.

EXPECTATIONS OF A QUALITY PROFESSIONAL

1. **Act with Integrity and Honesty**
    1. Strive to uphold and advance the integrity, honor, and dignity of the Quality profession.
    2. Be truthful and transparent in all professional interactions and activities.
    3. Execute professional responsibilities and make decisions in an objective, factual, and fully informed manner.

4. Accurately represent and do not mislead others regarding professional qualifications, including education, titles, affiliations, and certifications.
5. Offer services, provide advice, and undertake assignments only in your areas of competence, expertise, and training.

2. Demonstrate Responsibility, Respect, and Fairness

1. Hold paramount the safety, health, and welfare of individuals, the public, and the environment.
2. Avoid conduct that unjustly harms or threatens the reputation of the Society, its members, or the Quality profession.
3. Do not intentionally cause harm to others through words or deeds. Treat others fairly, courteously, with dignity, and without prejudice or discrimination.
4. Act and conduct business in a professional and socially responsible manner.
5. Allow diversity in the opinions and personal lives of others.

3. Safeguard Proprietary Information and Avoid Conflicts of Interest

1. Ensure the protection and integrity of confidential information.
2. Do not use confidential information for personal gain.
3. Fully disclose and avoid any real or perceived conflicts of interest that could reasonably impair objectivity or independence in the service of clients, customers, employers, or the Society.
4. Give credit where it is due.
5. Do not plagiarize. Do not use the intellectual property of others without permission. Document the permission as it is obtained.

Appendix B

Six Sigma Green Belt Body of Knowledge Map 2014–2022

The Certified Six Sigma Green Belt (CSSGB) Body of Knowledge (BoK) has been updated to ensure that the most current state of Six Sigma Green Belt practice is being tested in the examination. If you would like more information on how a BoK is updated, see a description of the process on the ASQ website (www.asq.org).

Part of the updating process is to conduct a job analysis survey to determine whether the topics in the 2014 BoK are still relevant to the job role of Six Sigma Green Belts and to identify any new topics that have emerged since that BoK was developed. The results of the CSSGB job analysis survey showed that nearly all of the topics that were in the 2014 BoK are still relevant to the job roles of Six Sigma Green Belts in 2022.

The 2021 Certified Six Sigma Green Belt (CSSGB) BoK was introduced at the August 2022 administration.

GENERAL COMMENTS ABOUT ASQ BODY OF KNOWLEDGE UPDATES

When the Body of Knowledge (BoK) is updated for an ASQ exam, the majority of the material covered in the BoK remains the same. There are very few programs that change dramatically over a 5–7 year period. One of the points that we make to all of the exam development committees is that ASQ certification exams need to reflect "the state of practice" not "the state of the art"—this helps to keep the programs grounded in what people currently do, rather than being driven by the latest hot-topic improvement idea or trend. Typically, the biggest change in any updated BoK is in how the content is organized. When a new BoK is announced and posted on the ASQ website, we also include a "BoK Map" that highlights the changes between the two bodies of knowledge, old and new. The BoK map also clearly identifies any new content that has been added to the exam, as well as any content that has been removed from the exam.

2014 BoK	2022 BoK Details	Notes
Section	**I. Overview: Six Sigma and the Organization [11 Questions]**	Number of questions changed from 13 to 11
	A. Six sigma and organizational goals	
I.A.1	1. Value of six sigma Recognize why organizations use six sigma, how they apply its philosophy and goals, and the evolution of six sigma from quality leaders such as Juran, Deming, Shewhart, Ishikawa, and others. (Understand)	
I.A.2	2. Organizational goals and six sigma projects Identify the linkages and supports that need to be established between a selected six sigma project and the organization's goals including SMART goals, and describe how process inputs, outputs, and feedback at all levels can influence the organization as a whole. (Understand)	Added SMART goals
I.A.3	3. Organizational drivers and metrics Recognize key business drivers (profit, market share, customer satisfaction, efficiency, product differentiation, key performance indicators (KPIs)) for all types of organizations. Understand how key metrics and scorecards are developed and how they impact the entire organization. (Understand)	Added key performance indicators (KPIs)
I.B	**B. Lean principles in the organization**	
I.B.1	1. Lean concepts Define and describe lean concepts such as theory of constraints, value chain, flow, takt time, just-in-time (JIT), Gemba, spaghetti diagrams, and perfection. (Apply)	Added takt time, just-in-time (JIT), Gemba and spaghetti diagrams
I.B.2	2. Value-stream mapping Use value-stream mapping to identify value-added processes and steps or processes that produce waste, including excess inventory, unused space, test inspection, rework, transportation, and storage. (Understand)	
I.C	**C. Design for six sigma (DFSS) methodologies**	
I.C.1	1. Road maps for DFSS Distinguish between DMADV (define, measure, analyze, design, verify) and IDOV (identify, design, optimize, verify), and recognize how they align with DMAIC. Describe how these methodologies are used for improving the end product or process during the design (DFSS) phase. Understand how verification and validation are used to compare results against stated goals. (Understand)	Added verification and validation
I.C.2	2. Basic failure mode and effects analysis (FMEA) Use FMEA to evaluate a process or product and determine what might cause it to fail and the effects that failure could have. Identify and use scale criteria, calculate the risk priority number (RPN), and analyze the results. (Analyze)	
I.C.3	3. Design FMEA and process FMEA Define and distinguish between these two uses of FMEA. (Apply)	

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2014 BoK	2022 BoK Details	Notes
	II. Define Phase [20 Questions]	Number of questions changed from 23 to 20
	A. Project identification	
II.A.1	1. Project selection Describe the project selection process and what factors should be considered in deciding whether to use the six sigma DMAIC methodology or another problem-solving process. (Understand)	
II.A.2	2. Process elements Define and describe process components and boundaries. Recognize how processes cross various functional areas and the challenges that result for process improvement efforts. (Analyze)	
II.A.3	3. Benchmarking Understand various types of benchmarking, including competitive, collaborative and best practices. (Understand)	
II.A.4	4. Process inputs and outputs Identify process input and output variables and evaluate their relationships using the supplier, inputs, process, output, customer (SIPOC) model. (Analyze)	
II.A.5	5. Owners and stakeholders Identify the process owners and other stakeholders in a project. (Apply)	
	B. Voice of the customer (VOC)	
II.B.1	1. Customer identification Identify the internal and external customers of a project, and what effect the project will have on them. (Apply)	
II.B.2	2. Customer data Collect feedback from customers using surveys, focus groups, interviews, and various forms of observation. Identify the key elements that make these tools effective. Review data collection questions to eliminate vagueness, ambiguity, and any unintended bias. (Apply)	
II.B.3	3. Customer requirements Use quality function deployment (QFD), Critical to X (CTX when 'X' can be quality, cost, safety, etc.), Critical to Quality tree (CTQ), and Kano model to translate customer requirements statements into product features, performance measures, or opportunities for improvement. Use weighting methods as needed to amplify the importance and urgency of different kinds of input; telephone call vs. survey response; product complaint vs. expedited service request. (Apply)	Added CTX, CTQ, and Kano model
	C. Project management basics	
NEW	1. Project methodology Define and apply agile and top-down project management methods. (Apply)	
II.C.1	2. Project charter Define and describe elements of a project charter and develop a problem statement that includes baseline data or current status to be improved and the project's goals. (Apply)	
II.C.2	3. Project scope Help define the scope of the project using process maps, Pareto charts, and other quality tools. (Apply)	

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2014 BoK	2022 BoK Details	Notes
II.C.3	4. Project metrics Help develop primary metrics (reduce defect levels by x-amount) and consequential metrics (the negative effects that making the planned improvement might cause). (Apply)	
II.C.4	5. Project planning tools Use work breakdown structures (WBS), Gantt charts, critical path method (CPM), program evaluation and review technique (PERT) charts, and toll-gate reviews to plan projects and monitor their progress. (Apply)	Added work breakdown structure (WBS), and toll-gate reviews
II.C.5	6. Project documentation Describe the types of data and input needed to document a project. Identify and help develop appropriate presentation tools (storyboards, spreadsheet summary of results) for phase reviews and management updates. (Apply)	
II.C.6	7. Project risk analysis and management Describe the elements of project risk analysis, including feasibility, potential impact, risk priority number (RPN), and risk management. Identify the potential effect risk can have on project goals and schedule, resources (materials and personnel), business continuity planning, costs and other financial measures, and stakeholders. (Understand)	Revised subtopic name; added risk management and business continuity planning
II.C.7	8. Project closure Review with team members and sponsors the project objectives achieved in relation to the charter and ensure that documentation is completed and stored appropriately. Identify lessons learned and inform other parts of the organization about opportunities for improvement. (Apply)	
II.D	**D. Management and planning tools** Define, select, and apply these tools: 1) affinity diagrams, 2) interrelationship digraphs, 3) tree diagrams, 4) prioritization matrices, 5) matrix diagrams, 6) process decision program charts (PDPC), 7) activity network diagrams, and 8) SWOT analysis. (Apply)	Added SWOT analysis
II.E	**E. Business results for projects**	
II.E.1	1. Process performance Calculate process performance metrics such as defects per unit (DPU), rolled throughput yield (RTY), cost of poor quality (COPQ), defects per million opportunities (DPMO), sigma levels, and process capability indices. Track process performance measures to drive project decisions. (Analyze)	
II.E.2	2. Communication Define and describe communication techniques used in organizations: top-down, bottom-up, and horizontal. (Apply)	
II.F	**F. Team dynamics and performance**	
II.F.1	1. Team stages and dynamics Define and describe the stages of team evolution, including forming, storming, norming, performing, adjourning, and recognition. Identify and help resolve negative dynamics such as overbearing, dominant, or reluctant participants, the unquestioned acceptance of opinions as facts, groupthink, feuding, floundering, the rush to accomplishment, attribution, discounts, digressions, and tangents. (Understand)	

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2014 BoK	**2022 BoK Details**	**Notes**
II.F.2	2. Team roles and responsibilities Use tools, such as RACI, to describe and define the roles and responsibilities of participants on six sigma and other teams, including black belt, master black belt, green belt, champion, executive, coach, facilitator, team member, sponsor, and process owner. (Apply)	Added RACI
II.F.3	3. Team tools and decision-making concepts Define and apply team tools such as brainstorming, and decision-making concepts such as nominal group technique, and multi-voting. (Apply)	Revised subtopic name and added decision-making concepts to subtext
II.F.4	4. Team communication Identify and use appropriate communication methods (both within the team and from the team to various stakeholders) to report progress, conduct reviews, and support the overall success of the project. (Apply)	
	III. Measure Phase [20 Questions]	Number of questions changed from 23 to 20
III.A	**A. Process analysis and documentation** Develop process maps and review written procedures, work instructions, and flowcharts to identify any gaps or areas of the process that are misaligned. (Create)	
III.B	**B. Probability and statistics**	
III.B.1	1. Basic probability concepts Describe and interpret basic probability concepts: independent events, mutually exclusive events, multiplication rules, permutations, and combinations. (Understand)	
III.B.2	2. Central limit theorem Define the central limit theorem and describe its significance in relation to confidence intervals, hypothesis testing, and control charts. (Understand)	
III.C	**C. Statistical distributions** Define and describe various distributions as they apply to statistical process control and probability: normal, binomial, Poisson, chi square, Student's t, and F. (Understand)	
III.D	**D. Collecting and summarizing data**	
III.D.1	1. Types of data and measurement scales Identify and classify continuous (variables) and discrete (attributes) data. Describe and define nominal, ordinal, interval, and ratio measurement scales. (Analyze)	
III.D.2	2. Sampling and data collection plans and methods Define and apply various sampling methods (random and stratified) and data collection methods (check sheets and data coding). Prepare data collection plans that include gathering data and performing quality checks (e.g., minimum/maximum values, erroneous data, null values). (Apply)	Revised subtopic name and added data collection plans and quality checks
III.D.3	3. Descriptive statistics Define, calculate, and interpret measures of dispersion and central tendency. Develop and interpret frequency distributions and cumulative frequency distributions. (Evaluate)	

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2014 BoK	2022 BoK Details	Notes
III.D.4	4. Graphical methods Construct and interpret diagrams and charts that are designed to communicate numerical analysis efficiently, including scatter diagrams, normal probability plots, histograms, stem-and-leaf plots, box-and-whisker plots. (Create)	
III.E	**E. Measurement system analysis (MSA)** Calculate, analyze, and interpret measurement system capability using gauge repeatability and reproducibility (GR&R) studies, measurement correlation, bias, linearity, percent agreement, and precision/tolerance (P/T). (Evaluate)	
III.F	**F. Process and performance capability**	
III.F.1	1. Process performance vs. process specifications Define and distinguish between natural process limits and specification limits, and calculate process performance metrics. (Evaluate)	
III.F.2	2. Process capability studies Define, describe, and conduct process capability studies, including identifying characteristics, specifications, and tolerances, and verifying stability and normality. (Evaluate)	
III.F.3	3. Process capability (C_p, C_{pk}) and process performance (P_p, P_{pk}) indices Describe the relationship between these types of indices. Define, select, and calculate process capability and process performance. Describe when C_{pm} measures can be used. Calculate the sigma level of a process. (Evaluate)	
III.F.4	4. Short-term vs. long-term capability and sigma shift Describe the assumptions and conventions that are appropriate to use when only short-term data are used. Identify and calculate the sigma shift that occurs when long- and short-term data are compared. (Evaluate)	
	IV. Analyze Phase [18 Questions]	Number of questions changed from 15 to 18
IV.A	**A. Exploratory data analysis**	
IV.A.1	1. Multi-vari studies Select appropriate sampling plans to create multi-vari study charts and interpret the results for positional, cyclical, and temporal variation. (Create)	
IV.A.2	2. Correlation and linear regression Describe the difference between correlation and causation. Calculate the correlation coefficient and linear regression and interpret the results in terms of statistical significance (p-value). Use regression models for estimation and prediction. (Evaluate)	
IV.B	**B. Hypothesis testing**	
IV.B.1	1. Basics Distinguish between statistical and practical significance. Determine appropriate sample sizes and develop tests for significance level, power, and type I and type II errors. (Apply)	

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2014 BoK	2022 BoK Details	Notes
IV.B.2	2. Tests for means, variances, and proportions Conduct hypothesis tests to compare means, variances, and proportions (paired-comparison t-test, F-test, analysis of variance (ANOVA), chi square) and interpret the results. (Analyze)	
NEW	**C. Additional analysis methods**	
NEW	1. Gap analysis Analyze scenarios to identify performance gaps and compare current and future states using predefined metrics. (Analyze)	
V.B	2. Root cause analysis Use cause and effect diagrams, relational matrices, 5 Whys, fault tree analysis, and other problem-solving tools to identify the true cause of a problem. (Analyze)	
	V. Improve Phase [16 Questions]	Number of questions changed from 15 to 16
	A. Design of experiments (DOE)	
V.A.1	1. Basic terms Define and describe terms such as independent and dependent variables, factors and levels, responses, treatments, errors, repetition, blocks, randomization, effects, and replication. (Understand)	
V.A.2	2. DOE graphs and plots Interpret main effects analysis and interaction plots. (Apply)	
NEW	**B. Implementation planning** Apply implementation planning by using proof of concept, try-storming, simulations, and conducting pilot tests. (Apply)	
	C. Lean tools	
V.C.1	1. Waste elimination Select and apply tools and techniques for eliminating or preventing waste, including pull systems, kanban, 5S, standard work, and poka-yoke. (Apply)	
V.C.2	2. Cycle-time reduction Use various techniques to reduce cycle time (continuous flow, setup reduction), single-minute exchange of dies (SMED). (Analyze)	Added SMED
V.C.3	3. Kaizen and kaizen blitz Define and distinguish between these two methods and apply them in various situations. (Apply)	
	VI. Control Phase [15 Questions]	Number of questions changed from 11 to 15
VI.A	**A. Statistical process control (SPC)**	
VI.A.1	1. SPC Basics Describe the theory and objectives of SPC, including measuring and monitoring process performance for both continuous and discrete data. Define and distinguish between common and special cause variation and how these conditions can be deduced from control chart analysis. (Analyze)	
VI.A.2	2. Rational subgrouping Define and describe how rational subgrouping is used. (Understand)	

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2014 BoK	2022 BoK Details	Notes
VI.A.3	3. Control charts Identify, select, construct, and use control charts: $\bar{X}$–R, $\bar{X}$–s, individual and moving range (ImR or XmR), median, p, np, c, and u. (Apply)	
NEW	**B. Sustain improvements**	
VI.B	1. Control plan Assist in developing and implementing a control plan to document and monitor the process. (Apply)	Removed “maintain the improvements”
NEW	2. Document control Understand document control and its role in controlling and sustaining improvements. (Understand)	
NEW	3. Training plans Develop training plans to implement and sustain improvements. (Apply)	
NEW	4. Audits Define first-, second-, and third-party audits. (Remember)	
NEW	5. Plan-do-check-act (PDCA) Apply and distinguish between the steps of plan-do-check-act (PDCA). (Apply)	
VI.C	**C. Lean tools for process control**	
VI.C.1	1. Total productive maintenance (TPM) Define the elements of TPM, including use of predictive maintenance and describe how they can be used to control the improved process. (Understand)	Added predictive maintenance
VI.C.2	2. Visual factory Define the elements of a visual factory (Andon, Jidoka) and describe how they can be used to control the improved process. (Understand)	Added Andon and Jidoka as examples

Appendix C

ASQ Certified Six Sigma Green Belt (CSSGB) Body of Knowledge (2022)

Included in this body of knowledge (BOK) are explanations (subtext) and cognitive levels for each topic or subtopic in the test. These details will be used by the Examination Development Committee as guidelines for writing test questions and are designed to help candidates prepare for the exam by identifying specific content within each topic that can be tested. Except where specified, the subtext is not intended to limit the subject or be all-inclusive of what might be covered in an exam but is intended to clarify how topics are related to the role of the Certified Six Sigma Green Belt (SSGB). The descriptor in parentheses at the end of each subtext entry refers to the highest cognitive level at which the topic will be tested. A complete description of cognitive levels is provided at the end of this document.

I. Overview: Six Sigma and the Organization (11 Questions)

A. Six sigma and organizational goals

1. Value of six sigma

Recognize why organizations use six sigma, how they apply its philosophy and goals, and the evolution of six sigma from quality leaders such as Juran, Deming, Shewhart, Ishikawa, and others. (Understand)

2. Organizational goals and six sigma projects

Identify the linkages and supports that need to be established between a selected six sigma project and the organization's goals including SMART goals, and describe how process inputs, outputs, and feedback at all levels can influence the organization as a whole. (Understand)

3. Organizational drivers and metrics

Recognize key business drivers (profit, market share, customer satisfaction, efficiency, product differentiation, key performance indicators (KPIs)) for all types of organizations. Understand how key metrics and scorecards are developed and how they impact the entire organization. (Understand)

B. Lean principles in the organization

1. Lean concepts

Define and describe lean concepts such as theory of constraints, value chain, flow, takt time, just-in-time (JIT), Gemba, spaghetti diagrams, and perfection. (Apply)

2. Value-streaming mapping

Use value-stream mapping to identify value-added processes and steps or processes that produce waste, including excess inventory, unused space, test inspection, rework, transportation, and storage. (Understand)

C. Design for six sigma (DFSS) methodologies

1. Road maps for DFSS

Distinguish between DMADV (define, measure, analyze, design, verify) and IDOV (identify, design, optimize, verify), and recognize how they align with DMAIC. Describe how these methodologies are used for improving the end product or process during the design (DFSS) phase. Understand how verification and validation are used to compare results against stated goals. (Understand)

2. Basic failure mode and effects analysis (FMEA)

Use FMEA to evaluate a process or product and determine what might cause it to fail and the effects that failure could have. Identify and use scale criteria, calculate the risk priority number (RPN), and analyze the results. (Analyze)

3. Design FMEA and process FMEA

Define and distinguish between these two uses of FMEA. (Apply)

II. Define Phase (20 Questions)

A. Project identification

1. Project selection

Describe the project selection process and what factors should be considered in deciding whether to use the six sigma DMAIC methodology or another problem-solving process. (Understand)

2. Process elements

Define and describe process components and boundaries. Recognize how processes cross various functional areas and the challenges that result for process improvement efforts. (Analyze)

3. Benchmarking

Understand various types of benchmarking, including competitive, collaborative, and best practices. (Understand)

4. **Process inputs and outputs**

   Identify process input and output variables and evaluate their relationships using the supplier, inputs, process, output, customer (SIPOC) model. (Analyze)

5. **Owners and stakeholders**

   Identify the process owners and other stakeholders in a project. (Apply)

B. **Voice of the customer (VOC)**

1. **Customer identification**

   Identify the internal and external customers of a project, and what effect the project will have on them. (Apply)

2. **Customer data**

   Collect feedback from customers using surveys, focus groups, interviews, and various forms of observation. Identify the key elements that make these tools effective. Review data collection questions to eliminate vagueness, ambiguity, and any unintended bias. (Apply)

3. **Customer requirements**

   Use quality function deployment (QFD), Critical to X (CTX when 'X' can be quality, cost, safety, etc.), Critical to Quality tree (CTQ), and Kano model to translate customer requirements statements into product features, performance measures, or opportunities for improvement. Use weighting methods as needed to amplify the importance and urgency of different kinds of input; telephone call vs. survey response; product complaint vs. expedited service request. (Apply)

C. **Project management basics**

1. **Project methodology**

   Define and apply agile and top-down project management methods. (Apply)

2. **Project charter**

   Define and describe elements of a project charter and develop a problem statement that includes baseline data or current status to be improved and the project's goals. (Apply)

3. **Project scope**

   Help define the scope of the project using process maps, Pareto charts, and other quality tools. (Apply)

4. **Project metrics**

   Help develop primary metrics (reduce defect levels by x-amount) and consequential metrics (the negative effects that making the planned improvement might cause). (Apply)

5. **Project planning tools**

   Use work breakdown structures (WBS), Gantt charts, critical path method (CPM), program evaluation and review technique (PERT) charts, and toll-gate reviews to plan projects and monitor their progress. (Apply)

6. **Project documentation**

   Describe the types of data and input needed to document a project. Identify and help develop appropriate presentation tools (storyboards, spreadsheet summary of results) for phase reviews and management updates. (Apply)

7. **Project risk analysis and management**

   Describe the elements of project risk analysis, including feasibility, potential impact, risk priority number (RPN), and risk management. Identify the potential effect risk can have on project goals and schedule, resources (materials and personnel), business continuity planning, costs and other financial measures, and stakeholders. (Understand)

8. **Project closure**

   Review with team members and sponsors the project objectives achieved in relation to the charter and ensure that documentation is completed and stored appropriately. Identify lessons learned and inform other parts of the organization about opportunities for improvement. (Apply)

D. **Management and planning tools**

Define, select, and apply these tools: 1) affinity diagrams, 2) interrelationship digraphs, 3) tree diagrams, 4) prioritization matrices, 5) matrix diagrams, 6) process decision program charts (PDPC), 7) activity network diagrams, and 8) SWOT analysis. (Apply)

E. **Business results for projects**

1. **Process performance**

   Calculate process performance metrics such as defects per unit (DPU), rolled throughput yield (RTY), cost of poor quality (COPQ), defects per million opportunities (DPMO), sigma levels, and process capability indices. Track process performance measures to drive project decisions. (Analyze)

2. Communication

Define and describe communication techniques used in organizations: top-down, bottom-up, and horizontal. (Apply)

F. Team dynamics and performance

1. Team stages and dynamics

Define and describe the stages of team evolution, including forming, storming, norming, performing, adjourning, and recognition. Identify and help resolve negative dynamics such as overbearing, dominant, or reluctant participants, the unquestioned acceptance of opinions as facts, groupthink, feuding, floundering, the rush to accomplishment, attribution, discounts, digressions, and tangents. (Understand)

2. Team roles and responsibilities

Use tools, such as RACI, to describe and define the roles and responsibilities of participants on six sigma and other teams, including black belt, master black belt, green belt, champion, executive, coach, facilitator, team member, sponsor, and process owner. (Apply)

3. Team tools and decision-making concepts

Define and apply team tools such as brainstorming, and decision-making concepts such as nominal group technique, and multi-voting. (Apply)

4. Team communication

Identify and use appropriate communication methods (both within the team and from the team to various stakeholders) to report progress, conduct reviews, and support the overall success of the project. (Apply)

III. Measure Phase (20 Questions)

A. Process analysis and documentation

Develop process maps and review written procedures, work instructions, and flowcharts to identify any gaps or areas of the process that are misaligned. (Create)

B. Probability and statistics

1. Basic probability concepts

Identify and use basic probability concepts: independent events, mutually exclusive events, multiplication rules, permutations, and combinations. (Apply)

2. **Central limit theorem**

   Define the central limit theorem and describe its significance in relation to confidence intervals, hypothesis testing, and control charts. (Understand)

C. Statistical distributions

Define and describe various distributions as they apply to statistical process control and probability: normal, binomial, Poisson, chi square, Student's t, and F. (Understand)

D. Collecting and summarizing data

1. **Types of data and measurement scales**

   Identify and classify continuous (variables) and discrete (attributes) data. Describe and define nominal, ordinal, interval, and ratio measurement scales. (Analyze)

2. **Sampling and data collection plans and methods**

   Define and apply various sampling methods (random and stratified) and data collection methods (check sheets and data coding). Prepare data collection plans that include gathering data and performing quality checks (e.g., minimum/maximum values, erroneous data, null values). (Apply)

3. **Descriptive statistics**

   Define, calculate, and interpret measures of dispersion and central tendency. Develop and interpret frequency distributions and cumulative frequency distributions. (Evaluate)

4. **Graphical methods**

   Construct and interpret diagrams and charts that are designed to communicate numerical analysis efficiently, including scatter diagrams, normal probability plots, histograms, stem-and-leaf plots, box-and-whisker plots. (Create)

E. Measurement system analysis (MSA)

Calculate, analyze, and interpret measurement system capability using gauge repeatability and reproducibility (GR&R) studies, measurement correlation, bias, linearity, percent agreement, and precision/tolerance (P/T). (Evaluate)

F. Process and performance capability

1. **Process performance vs. process specifications**

   Define and distinguish between natural process limits and specification limits, and calculate process performance metrics. (Evaluate)

2. **Process capability studies**

   Define, describe, and conduct process capability studies, including identifying characteristics, specifications, and tolerances, and verifying stability and normality. (Evaluate)

3. **Process capability (C_p, C_{pk}) and process performance (P_p, P_{pk}) indices**

   Describe the relationship between these types of indices. Define, select, and calculate process capability and process performance. Describe when C_{pm} measures can be used. Calculate the sigma level of a process. (Evaluate)

4. **Short-term vs. long-term capability and sigma shift**

   Describe the assumptions and conventions that are appropriate to use when only short-term data are used. Identify and calculate the sigma shift that occurs when long- and short-term data are compared. (Evaluate)

IV. Analyze Phase (18 Questions)

A. Exploratory data analysis

1. **Multi-vari studies**

   Select appropriate sampling plans to create multi-vari study charts and interpret the results for positional, cyclical, and temporal variation. (Create)

2. **Correlation and linear regression**

   Describe the difference between correlation and causation. Calculate the correlation coefficient and linear regression and interpret the results in terms of statistical significance (p-value). Use regression models for estimation and prediction. (Evaluate)

B. Hypothesis testing

1. **Basics**

   Distinguish between statistical and practical significance. Determine appropriate sample sizes and develop tests for significance level, power, and type I and type II errors. (Apply)

2. **Tests for means, variances, and proportions**

   Conduct hypothesis tests to compare means, variances, and proportions (paired-comparison t-test, F-test, analysis of variance (ANOVA), chi square) and interpret the results. (Analyze)

C. Additional analysis methods

1. Gap analysis

Analyze scenarios to identify performance gaps and compare current and future states using predefined metrics. (Analyze)

2. Root cause analysis

Use cause and effect diagrams, relational matrices, 5 Whys, fault tree analysis, and other problem-solving tools to identify the true cause of a problem. (Analyze)

V. Improve Phase (16 Questions)

A. Design of experiments (DOE)

1. Basic terms

Define and describe terms such as independent and dependent variables, factors and levels, responses, treatments, errors, repetition, blocks, randomization, effects, and replication. (Understand)

2. DOE graphs and plots

Interpret main effects analysis and interaction plots. (Apply)

B. Implementation planning

Apply implementation planning by using proof of concepts, try-storming simulations, and pilot tests. (Apply)

C. Lean tools

1. Waste elimination

Select and apply tools and techniques for eliminating or preventing waste, including pull systems, kanban, 5S, standard work, and poka-yoke. (Apply)

2. Cycle-time reduction

Use various techniques to reduce cycle time (continuous flow, setup reduction, single-minute exchange of dies (SMED)). (Analyze)

3. Kaizen and kaizen blitz

Define and distinguish between these two methods and apply them in various situations. (Apply)

VI. Control Phase (15 Questions)

A. Statistical process control (SPC)

1. SPC Basics

Describe the theory and objectives of SPC, including measuring and monitoring process performance for both continuous and discrete data. Define and distinguish between common and special cause variation and how these conditions can be deduced from control chart analysis. (Analyze)

2. **Rational subgrouping**

   Define and describe how rational subgrouping is used. (Understand)

3. **Control charts**

   Identify, select, construct, and use control charts: $\bar{X}$–R, $\bar{X}$–s, individual and moving range (ImR or XmR), median, p, np, c, and u. (Apply)

B. **Sustain improvements**

1. **Control plan**

   Assist in developing and implementing a control plan to document and monitor the process. (Apply)

2. **Document control**

   Understand document control and its role in controlling and sustaining improvements. (Understand)

3. **Training plans**

   Develop training plans to implement and sustain improvements. (Apply)

4. **Audits**

   Define first-, second-, and third-party audits. (Remember)

5. **Plan-do-check-act (PDCA)**

   Apply and distinguish between the steps of plan-do-check-act (PDCA). (Apply)

C. **Lean tools for process control**

1. **Total productive maintenance (TPM)**

   Define the elements of TPM, including use of predictive maintenance and describe how they can be used to control the improved process. (Understand)

2. **Visual factory**

   Define the elements of a visual factory (Andon, Jidoka) and describe how they can be used to control the improved process. (Understand)

LEVELS OF COGNITION BASED ON BLOOM'S TAXONOMY—REVISED (2001)

In addition to *content* specifics, the subtext detail also indicates the intended *complexity level* of the test questions for that topic. These levels are based on the Revised "Levels of Cognition" (from Bloom's Taxonomy, 2001) and are presented below in rank order, from least complex to most complex.

Remember

Be able to remember or recognize terminology, definitions, facts, ideas, materials, patterns, sequences, methodologies, principles, etc. (Also commonly referred to as recognition, recall, or rote knowledge)

Understand

Be able to read and understand descriptions, communications, reports, tables, diagrams, directions, regulations, etc.

Apply

Be able to apply ideas, procedures, methods, formulas, principles, theories, etc., in job-related situations.

Analyze

Be able to break down information into its constituent parts and recognize the parts' relationship to one another and how they are organized; identify sublevel factors or salient data from a complex scenario.

Evaluate

Be able to make judgments regarding the value of proposed ideas, solutions, methodologies, etc., by using appropriate criteria or standards to estimate accuracy, effectiveness, economic benefits, etc.

Create

Be able to put parts or elements together in such a way as to show a pattern or structure not clearly there before; able to identify which data or information from a complex set is appropriate to examine further or from which supported conclusions can be drawn.

Appendix D

Control Limit Formulas

VARIABLES CHARTS

$\bar{x}$ and R chart:

$$\textit{Averages chart}: \bar{\bar{x}} \pm A_2\bar{R} \qquad \textit{Range chart}: LCL = D_3\bar{R} \quad UCL = D_4\bar{R}$$

$\bar{x}$ and s chart:

$$\textit{Averages chart}: \bar{\bar{x}} \pm A_3\bar{s} \qquad \textit{Standard deviation chart}: LCL = B_3\bar{s} \quad UCL = B_4\bar{s}$$

Individuals and moving range chart (two-value moving window):

$$\textit{Individuals chart}: \bar{x} \pm 2.66\bar{R} \quad \textit{Moving range}: UCL = 3.267\bar{R}$$

Moving average and moving range (two-value moving window):

$$\textit{Moving average}: \bar{\bar{x}} \pm 1.88\bar{R} \quad \textit{Moving range}: UCL = 3.267\bar{R}$$

Median chart:

$$\textit{Median chart}: \bar{x}' \pm A_2'\bar{R} \qquad \textit{Range chart}: LCL = D_3\bar{R} \quad UCL = D_4\bar{R}$$

ATTRIBUTES CHARTS

Variable sample size:		Constant sample size:	
p chart:	$\bar{p} \pm 3\sqrt{\dfrac{\bar{p}(1-\bar{p})}{\bar{n}}}$	np chart:	$n\bar{p} \pm 3\sqrt{n\bar{p}(1-\bar{p})}$
u chart:	$\bar{u} \pm 3\sqrt{\dfrac{\bar{u}}{\bar{n}}}$	c chart:	$\bar{c} \pm 3\sqrt{\bar{c}}$
D chart:	$\bar{D} \pm 3\sigma_D$	U chart:	$\bar{U} \pm 3\sigma_U$

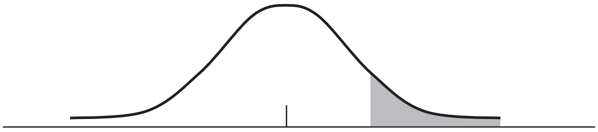
Appendix E

Constants for Control Charts

Subgroup size										A_2 for median charts	
N	A_2	d_2	D_3	D_4	A_3	c_4	B_3	B_4	E_2		A_4
2	1.880	1.128	–	3.267	2.659	0.798	–	3.267	2.660	1.880	2.224
3	1.023	1.693	–	2.574	1.954	0.886	–	2.568	1.772	1.187	1.091
4	0.729	2.059	–	2.282	1.628	0.921	–	2.266	1.457	0.796	0.758
5	0.577	2.326	–	2.114	1.427	0.940	–	2.089	1.290	0.691	0.594
6	0.483	2.534	–	2.004	1.287	0.952	0.030	1.970	1.184	0.548	0.495
7	0.419	2.704	0.076	1.924	1.182	0.959	0.118	1.882	1.109	0.508	0.429
8	0.373	2.847	0.136	1.864	1.099	0.965	0.185	1.815	1.054	0.433	0.380
9	0.337	2.970	0.184	1.816	1.032	0.969	0.239	1.761	1.010	0.412	0.343
10	0.308	3.078	0.223	1.777	0.975	0.973	0.284	1.716	0.975	0.362	0.314

Appendix F

Areas Under Standard Normal Curve



z	**0.00**	**0.01**	**0.02**	**0.03**	**0.04**
0.0	0.50000000000	0.49601064369	0.49202168628	0.48803352659	0.48404656315
0.1	0.46017216272	0.45620468746	0.45224157398	0.44828321335	0.44432999519
0.2	0.42074029056	0.41683383652	0.41293557735	0.40904588486	0.40516512830
0.3	0.38208857781	0.37828047818	0.37448416528	0.37069998106	0.36692826396
0.4	0.34457825839	0.34090297377	0.33724272685	0.33359782060	0.32996855366
0.5	0.30853753873	0.30502573090	0.30153178755	0.29805596539	0.29459851622
0.6	0.27425311775	0.27093090378	0.26762889347	0.26434729212	0.26108629969
0.7	0.24196365222	0.23885206809	0.23576249778	0.23269509230	0.22964999716
0.8	0.21185539858	0.20897008787	0.20610805359	0.20326939183	0.20045419326
0.9	0.18406012535	0.18141125489	0.17878637961	0.17618554225	0.17360878034
1.0	0.15865525393	0.15624764502	0.15386423037	0.15150500279	0.14916995033
1.1	0.13566606095	0.13349951324	0.13135688104	0.12923811224	0.12714315056
1.2	0.11506967022	0.11313944644	0.11123243745	0.10934855243	0.10748769707
1.3	0.09680048459	0.09509791780	0.09341750899	0.09175913565	0.09012267246
1.4	0.08075665923	0.07926984145	0.07780384053	0.07635850954	0.07493369953
1.5	0.06680720127	0.06552171209	0.06425548782	0.06300836446	0.06178017671
1.6	0.05479929170	0.05369892815	0.05261613845	0.05155074849	0.05050258347
1.7	0.04456546276	0.04363293652	0.04271622079	0.04181513761	0.04092950898
1.8	0.03593031911	0.03514789358	0.03437950245	0.03362496942	0.03288411866
1.9	0.02871655982	0.02806660666	0.02742894970	0.02680341888	0.02618984494
2.0	0.02275013195	0.02221559443	0.02169169377	0.02117826964	0.02067516287
2.1	0.01786442056	0.01742917794	0.01700302265	0.01658580668	0.01617738337
2.2	0.01390344751	0.01355258115	0.01320938381	0.01287372144	0.01254546144
2.3	0.01072411002	0.01044407706	0.01017043867	0.00990307556	0.00964186995
2.4	0.00819753592	0.00797626026	0.00776025355	0.00754941142	0.00734363096
2.5	0.00620966533	0.00603655808	0.00586774172	0.00570312633	0.00554262344
2.6	0.00466118802	0.00452711113	0.00439648835	0.00426924341	0.00414530136
2.7	0.00346697380	0.00336416041	0.00326409582	0.00316671628	0.00307195922
2.8	0.00255513033	0.00247707500	0.00240118247	0.00232740021	0.00225567669
2.9	0.00186581330	0.00180714378	0.00175015693	0.00169481002	0.00164106123

Continued

Continued

z	**0.00**	**0.01**	**0.02**	**0.03**	**0.04**
3.0	0.00134989803	0.00130623845	0.00126387343	0.00122276869	0.00118289074
3.1	0.00096760321	0.00093543672	0.00090425520	0.00087403152	0.00084473917
3.2	0.00068713794	0.00066367486	0.00064095298	0.00061895109	0.00059764850
3.3	0.00048342414	0.00046647986	0.00045008724	0.00043422992	0.00041889195
3.4	0.00033692927	0.00032481440	0.00031310568	0.00030179062	0.00029085709
3.5	0.00023262908	0.00022405335	0.00021577340	0.00020777983	0.00020006352
3.6	0.00015910859	0.00015309850	0.00014730151	0.00014171061	0.00013631902
3.7	0.00010779973	0.00010362962	0.00009961139	0.00009573989	0.00009201013
3.8	0.00007234804	0.00006948340	0.00006672584	0.00006407163	0.00006151716
3.9	0.00004809634	0.00004614806	0.00004427448	0.00004247293	0.00004074080
4.0	0.00003167124	0.00003035937	0.00002909907	0.00002788843	0.00002672560
4.1	0.00002065751	0.00001978296	0.00001894362	0.00001813816	0.00001736529
4.2	0.00001334575	0.00001276853	0.00001221512	0.00001168457	0.00001117599
4.3	0.00000853991	0.00000816273	0.00000780146	0.00000745547	0.00000712414
4.4	0.00000541254	0.00000516853	0.00000493505	0.00000471165	0.00000449794
4.5	0.00000339767	0.00000324138	0.00000309198	0.00000294918	0.00000281271
4.6	0.00000211245	0.00000201334	0.00000191870	0.00000182833	0.00000174205
4.7	0.00000130081	0.00000123858	0.00000117922	0.00000112260	0.00000106859
4.8	0.00000079333	0.00000075465	0.00000071779	0.00000068267	0.00000064920
4.9	0.00000047918	0.00000045538	0.00000043272	0.00000041115	0.00000039061
5.0	0.00000028665	0.00000027215	0.00000025836	0.00000024524	0.00000023277
5.1	0.00000016983	0.00000016108	0.00000015277	0.00000014487	0.00000013737
5.2	0.00000009964	0.00000009442	0.00000008946	0.00000008476	0.00000008029
5.3	0.00000005790	0.00000005481	0.00000005188	0.00000004911	0.00000004647
5.4	0.00000003332	0.00000003151	0.00000002980	0.00000002818	0.00000002664
5.5	0.00000001899	0.00000001794	0.00000001695	0.00000001601	0.00000001512
5.6	0.00000001072	0.00000001012	0.00000000955	0.00000000901	0.00000000850
5.7	0.00000000599	0.00000000565	0.00000000533	0.00000000502	0.00000000473
5.8	0.00000000332	0.00000000312	0.00000000294	0.00000000277	0.00000000261
5.9	0.00000000182	0.00000000171	0.00000000161	0.00000000151	0.00000000143
6.0	0.00000000099	0.00000000093	0.00000000087	0.00000000082	0.00000000077

Continued

Continued

z	0.05	0.06	0.07	0.08	0.09
0.0	0.48006119416	0.47607781735	0.47209682982	0.46811862799	0.46414360741
0.1	0.44038230763	0.43644053711	0.43250506832	0.42857628410	0.42465456527
0.2	0.40129367432	0.39743188680	0.39358012680	0.38973875244	0.38590811880
0.3	0.36316934882	0.35942356678	0.35569124520	0.35197270758	0.34826827346
0.4	0.32635522029	0.32275811025	0.31917750878	0.31561369652	0.31206694942
0.5	0.29115968679	0.28773971885	0.28433884905	0.28095730890	0.27759532475
0.6	0.25784611081	0.25462691467	0.25142889510	0.24825223045	0.24509709367
0.7	0.22662735238	0.22362729244	0.22064994634	0.21769543759	0.21476388416
0.8	0.19766254312	0.19489452125	0.19215020210	0.18942965478	0.18673294304
0.9	0.17105612631	0.16852760747	0.16602324606	0.16354305933	0.16108705951
1.0	0.14685905638	0.14457229966	0.14230965436	0.14007109009	0.13785657203
1.1	0.12507193564	0.12302440305	0.12100048442	0.11900010746	0.11702319602
1.2	0.10564977367	0.10383468112	0.10204231507	0.10027256795	0.09852532905
1.3	0.08850799144	0.08691496195	0.08534345082	0.08379332242	0.08226443868
1.4	0.07352925961	0.07214503697	0.07078087699	0.06943662333	0.06811211797
1.5	0.06057075800	0.05937994059	0.05820755564	0.05705343324	0.05591740252
1.6	0.04947146803	0.04845722627	0.04745968180	0.04647865786	0.04551397732
1.7	0.04005915686	0.03920390329	0.03836357036	0.03753798035	0.03672695570
1.8	0.03215677480	0.03144276298	0.03074190893	0.03005403896	0.02937898004
1.9	0.02558805952	0.02499789515	0.02441918528	0.02385176434	0.02329546775
2.0	0.02018221541	0.01969927041	0.01922617223	0.01876276643	0.01830889985
2.1	0.01577760739	0.01538633478	0.01500342297	0.01462873078	0.01426211841
2.2	0.01222447266	0.01191062542	0.01160379152	0.01130384424	0.01101065832
2.3	0.00938670553	0.00913746753	0.00889404263	0.00865631903	0.00842418640
2.4	0.00714281074	0.00694685079	0.00675565261	0.00656911914	0.00638715476
2.5	0.00538614595	0.00523360816	0.00508492575	0.00494001576	0.00479879660
2.6	0.00402458854	0.00390703257	0.00379256235	0.00368110801	0.00357260095
2.7	0.00297976324	0.00289006808	0.00280281463	0.00271794492	0.00263540208
2.8	0.00218596145	0.00211820504	0.00205235899	0.00198837585	0.00192620913
2.9	0.00158886965	0.00153819521	0.00148899875	0.00144124192	0.00139488724

Continued

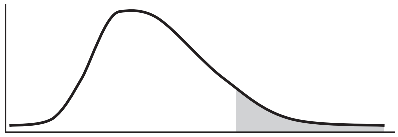
Continued

z	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**
3.0	0.00114420683	0.00110668496	0.00107029385	0.00103500297	0.00100078248
3.1	0.00081635231	0.00078884569	0.00076219469	0.00073637526	0.00071136397
3.2	0.00057702504	0.00055706107	0.00053773742	0.00051903543	0.00050093691
3.3	0.00040405780	0.00038971236	0.00037584092	0.00036242915	0.00034946312
3.4	0.00028029328	0.00027008769	0.00026022918	0.00025070689	0.00024151027
3.5	0.00019261558	0.00018542740	0.00017849061	0.00017179710	0.00016533898
3.6	0.00013112015	0.00012610762	0.00012127523	0.00011661698	0.00011212703
3.7	0.00008841729	0.00008495668	0.00008162377	0.00007841418	0.00007532364
3.8	0.00005905891	0.00005669351	0.00005441768	0.00005222823	0.00005012211
3.9	0.00003907560	0.00003747488	0.00003593632	0.00003445763	0.00003303665
4.0	0.00002560882	0.00002453636	0.00002350657	0.00002251785	0.00002156866
4.1	0.00001662376	0.00001591238	0.00001522998	0.00001457545	0.00001394772
4.2	0.00001068853	0.00001022135	0.00000977365	0.00000934467	0.00000893366
4.3	0.00000680688	0.00000650312	0.00000621233	0.00000593397	0.00000566753
4.4	0.00000429351	0.00000409798	0.00000391098	0.00000373215	0.00000356116
4.5	0.00000268230	0.00000255768	0.00000243862	0.00000232488	0.00000221623
4.6	0.00000165968	0.00000158105	0.00000150600	0.00000143437	0.00000136603
4.7	0.00000101708	0.00000096796	0.00000092113	0.00000087648	0.00000083391
4.8	0.00000061731	0.00000058693	0.00000055799	0.00000053043	0.00000050418
4.9	0.00000037107	0.00000035247	0.00000033476	0.00000031792	0.00000030190
5.0	0.00000022091	0.00000020963	0.00000019891	0.00000018872	0.00000017903
5.1	0.00000013024	0.00000012347	0.00000011705	0.00000011094	0.00000010515
5.2	0.00000007605	0.00000007203	0.00000006821	0.00000006459	0.00000006116
5.3	0.00000004398	0.00000004161	0.00000003937	0.00000003724	0.00000003523
5.4	0.00000002518	0.00000002381	0.00000002250	0.00000002127	0.00000002010
5.5	0.00000001428	0.00000001349	0.00000001274	0.00000001203	0.00000001135
5.6	0.00000000802	0.00000000757	0.00000000714	0.00000000673	0.00000000635
5.7	0.00000000446	0.00000000421	0.00000000396	0.00000000374	0.00000000352
5.8	0.00000000246	0.00000000231	0.00000000218	0.00000000205	0.00000000193
5.9	0.00000000134	0.00000000126	0.00000000119	0.00000000112	0.00000000105
6.0	0.00000000072	0.00000000068	0.00000000064	0.00000000060	0.00000000056

Appendix G

F Distributions

$F_{0.1}$



F distribution $F_{0.1}$

	Numerator degrees of freedom										
Denominator degrees of freedom	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	39.86	49.50	53.59	55.83	57.24	58.20	58.91	59.44	59.86	60.19	60.47
2	8.53	9.00	9.16	9.24	9.29	9.33	9.35	9.37	9.38	9.39	9.40
3	5.54	5.46	5.39	5.34	5.31	5.28	5.27	5.25	5.24	5.23	5.22
4	4.54	4.32	4.19	4.11	4.05	4.01	3.98	3.95	3.94	3.92	3.91
5	4.06	3.78	3.62	3.52	3.45	3.40	3.37	3.34	3.32	3.30	3.28
6	3.78	3.46	3.29	3.18	3.11	3.05	3.01	2.98	2.96	2.94	2.92
7	3.59	3.26	3.07	2.96	2.88	2.83	2.78	2.75	2.72	2.70	2.68
8	3.46	3.11	2.92	2.81	2.73	2.67	2.62	2.59	2.56	2.54	2.52
9	3.36	3.01	2.81	2.69	2.61	2.55	2.51	2.47	2.44	2.42	2.40
10	3.29	2.92	2.73	2.61	2.52	2.46	2.41	2.38	2.35	2.32	2.30
11	3.23	2.86	2.66	2.54	2.45	2.39	2.34	2.30	2.27	2.25	2.23
12	3.18	2.81	2.61	2.48	2.39	2.33	2.28	2.24	2.21	2.19	2.17
13	3.14	2.76	2.56	2.43	2.35	2.28	2.23	2.20	2.16	2.14	2.12
14	3.10	2.73	2.52	2.39	2.31	2.24	2.19	2.15	2.12	2.10	2.07
15	3.07	2.70	2.49	2.36	2.27	2.21	2.16	2.12	2.09	2.06	2.04
16	3.05	2.67	2.46	2.33	2.24	2.18	2.13	2.09	2.06	2.03	2.01
17	3.03	2.64	2.44	2.31	2.22	2.15	2.10	2.06	2.03	2.00	1.98
18	3.01	2.62	2.42	2.29	2.20	2.13	2.08	2.04	2.00	1.98	1.95
19	2.99	2.61	2.40	2.27	2.18	2.11	2.06	2.02	1.98	1.96	1.93
20	2.97	2.59	2.38	2.25	2.16	2.09	2.04	2.00	1.96	1.94	1.91
21	2.96	2.57	2.36	2.23	2.14	2.08	2.02	1.98	1.95	1.92	1.90
22	2.95	2.56	2.35	2.22	2.13	2.06	2.01	1.97	1.93	1.90	1.88
23	2.94	2.55	2.34	2.21	2.11	2.05	1.99	1.95	1.92	1.89	1.87
24	2.93	2.54	2.33	2.19	2.10	2.04	1.98	1.94	1.91	1.88	1.85
25	2.92	2.53	2.32	2.18	2.09	2.02	1.97	1.93	1.89	1.87	1.84
26	2.91	2.52	2.31	2.17	2.08	2.01	1.96	1.92	1.88	1.86	1.83
27	2.90	2.51	2.30	2.17	2.07	2.00	1.95	1.91	1.87	1.85	1.82
28	2.89	2.50	2.29	2.16	2.06	2.00	1.94	1.90	1.87	1.84	1.81
29	2.89	2.50	2.28	2.15	2.06	1.99	1.93	1.89	1.86	1.83	1.80
30	2.88	2.49	2.28	2.14	2.05	1.98	1.93	1.88	1.85	1.82	1.79
40	2.84	2.44	2.23	2.09	2.00	1.93	1.87	1.83	1.79	1.76	1.74
60	2.79	2.39	2.18	2.04	1.95	1.87	1.82	1.77	1.74	1.71	1.68
100	2.76	2.36	2.14	2.00	1.91	1.83	1.78	1.73	1.69	1.66	1.64

Continued

F distribution $F_{0.1}$ *(continued)*

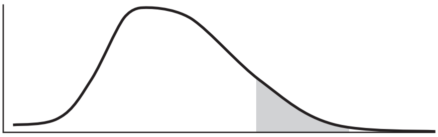
Denominator degrees of freedom	Numerator degrees of freedom										
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1	60.71	60.90	61.07	61.22	61.35	61.46	61.57	61.66	61.74	61.81	61.88
2	9.41	9.41	9.42	9.42	9.43	9.43	9.44	9.44	9.44	9.44	9.45
3	5.22	5.21	5.20	5.20	5.20	5.19	5.19	5.19	5.18	5.18	5.18
4	3.90	3.89	3.88	3.87	3.86	3.86	3.85	3.85	3.84	3.84	3.84
5	3.27	3.26	3.25	3.24	3.23	3.22	3.22	3.21	3.21	3.20	3.20
6	2.90	2.89	2.88	2.87	2.86	2.85	2.85	2.84	2.84	2.83	2.83
7	2.67	2.65	2.64	2.63	2.62	2.61	2.61	2.60	2.59	2.59	2.58
8	2.50	2.49	2.48	2.46	2.45	2.45	2.44	2.43	2.42	2.42	2.41
9	2.38	2.36	2.35	2.34	2.33	2.32	2.31	2.30	2.30	2.29	2.29
10	2.28	2.27	2.26	2.24	2.23	2.22	2.22	2.21	2.20	2.19	2.19
11	2.21	2.19	2.18	2.17	2.16	2.15	2.14	2.13	2.12	2.12	2.11
12	2.15	2.13	2.12	2.10	2.09	2.08	2.08	2.07	2.06	2.05	2.05
13	2.10	2.08	2.07	2.05	2.04	2.03	2.02	2.01	2.01	2.00	1.99
14	2.05	2.04	2.02	2.01	2.00	1.99	1.98	1.97	1.96	1.96	1.95
15	2.02	2.00	1.99	1.97	1.96	1.95	1.94	1.93	1.92	1.92	1.91
16	1.99	1.97	1.95	1.94	1.93	1.92	1.91	1.90	1.89	1.88	1.88
17	1.96	1.94	1.93	1.91	1.90	1.89	1.88	1.87	1.86	1.86	1.85
18	1.93	1.92	1.90	1.89	1.87	1.86	1.85	1.84	1.84	1.83	1.82
19	1.91	1.89	1.88	1.86	1.85	1.84	1.83	1.82	1.81	1.81	1.80
20	1.89	1.87	1.86	1.84	1.83	1.82	1.81	1.80	1.79	1.79	1.78
21	1.87	1.86	1.84	1.83	1.81	1.80	1.79	1.78	1.78	1.77	1.76
22	1.86	1.84	1.83	1.81	1.80	1.79	1.78	1.77	1.76	1.75	1.74
23	1.84	1.83	1.81	1.80	1.78	1.77	1.76	1.75	1.74	1.74	1.73
24	1.83	1.81	1.80	1.78	1.77	1.76	1.75	1.74	1.73	1.72	1.71
25	1.82	1.80	1.79	1.77	1.76	1.75	1.74	1.73	1.72	1.71	1.70
26	1.81	1.79	1.77	1.76	1.75	1.73	1.72	1.71	1.71	1.70	1.69
27	1.80	1.78	1.76	1.75	1.74	1.72	1.71	1.70	1.70	1.69	1.68
28	1.79	1.77	1.75	1.74	1.73	1.71	1.70	1.69	1.69	1.68	1.67
29	1.78	1.76	1.75	1.73	1.72	1.71	1.69	1.68	1.68	1.67	1.66
30	1.77	1.75	1.74	1.72	1.71	1.70	1.69	1.68	1.67	1.66	1.65
40	1.71	1.70	1.68	1.66	1.65	1.64	1.62	1.61	1.61	1.60	1.59
60	1.66	1.64	1.62	1.60	1.59	1.58	1.56	1.55	1.54	1.53	1.53
100	1.61	1.59	1.57	1.56	1.54	1.53	1.52	1.50	1.49	1.48	1.48

Continued

F* distribution $F_{0.1}$ *(continued)

	Numerator degrees of freedom										
Denominator degrees of freedom	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**40**	**60**	**100**
1	61.94	62.00	62.05	62.10	62.15	62.19	62.23	62.26	62.53	62.79	63.01
2	9.45	9.45	9.45	9.45	9.45	9.46	9.46	9.46	9.47	9.47	9.48
3	5.18	5.18	5.17	5.17	5.17	5.17	5.17	5.17	5.16	5.15	5.14
4	3.83	3.83	3.83	3.83	3.82	3.82	3.82	3.82	3.80	3.79	3.78
5	3.19	3.19	3.19	3.18	3.18	3.18	3.18	3.17	3.16	3.14	3.13
6	2.82	2.82	2.81	2.81	2.81	2.81	2.80	2.80	2.78	2.76	2.75
7	2.58	2.58	2.57	2.57	2.56	2.56	2.56	2.56	2.54	2.51	2.50
8	2.41	2.40	2.40	2.40	2.39	2.39	2.39	2.38	2.36	2.34	2.32
9	2.28	2.28	2.27	2.27	2.26	2.26	2.26	2.25	2.23	2.21	2.19
10	2.18	2.18	2.17	2.17	2.17	2.16	2.16	2.16	2.13	2.11	2.09
11	2.11	2.10	2.10	2.09	2.09	2.08	2.08	2.08	2.05	2.03	2.01
12	2.04	2.04	2.03	2.03	2.02	2.02	2.01	2.01	1.99	1.96	1.94
13	1.99	1.98	1.98	1.97	1.97	1.96	1.96	1.96	1.93	1.90	1.88
14	1.94	1.94	1.93	1.93	1.92	1.92	1.92	1.91	1.89	1.86	1.83
15	1.90	1.90	1.89	1.89	1.88	1.88	1.88	1.87	1.85	1.82	1.79
16	1.87	1.87	1.86	1.86	1.85	1.85	1.84	1.84	1.81	1.78	1.76
17	1.84	1.84	1.83	1.83	1.82	1.82	1.81	1.81	1.78	1.75	1.73
18	1.82	1.81	1.80	1.80	1.80	1.79	1.79	1.78	1.75	1.72	1.70
19	1.79	1.79	1.78	1.78	1.77	1.77	1.76	1.76	1.73	1.70	1.67
20	1.77	1.77	1.76	1.76	1.75	1.75	1.74	1.74	1.71	1.68	1.65
21	1.75	1.75	1.74	1.74	1.73	1.73	1.72	1.72	1.69	1.66	1.63
22	1.74	1.73	1.73	1.72	1.72	1.71	1.71	1.70	1.67	1.64	1.61
23	1.72	1.72	1.71	1.70	1.70	1.69	1.69	1.69	1.66	1.62	1.59
24	1.71	1.70	1.70	1.69	1.69	1.68	1.68	1.67	1.64	1.61	1.58
25	1.70	1.69	1.68	1.68	1.67	1.67	1.66	1.66	1.63	1.59	1.56
26	1.68	1.68	1.67	1.67	1.66	1.66	1.65	1.65	1.61	1.58	1.55
27	1.67	1.67	1.66	1.65	1.65	1.64	1.64	1.64	1.60	1.57	1.54
28	1.66	1.66	1.65	1.64	1.64	1.63	1.63	1.63	1.59	1.56	1.53
29	1.65	1.65	1.64	1.63	1.63	1.62	1.62	1.62	1.58	1.55	1.52
30	1.64	1.64	1.63	1.63	1.62	1.62	1.61	1.61	1.57	1.54	1.51
40	1.58	1.57	1.57	1.56	1.56	1.55	1.55	1.54	1.51	1.47	1.43
60	1.52	1.51	1.50	1.50	1.49	1.49	1.48	1.48	1.44	1.40	1.36
100	1.47	1.46	1.45	1.45	1.44	1.43	1.43	1.42	1.38	1.34	1.29

$F_{0.05}$



F distribution $F_{0.05}$

Denominator degrees of freedom	Numerator degrees of freedom										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5	241.9	243.0
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.40
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.76
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.94
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.70
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.03
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.60
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.31
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.10
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.94
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.82
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.72
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.63
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.57
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.51
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.46
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.41
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.37
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.34
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.31
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.28
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.26
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.24
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.22
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.20
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.18
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.17
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.15
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.14
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.13
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.04
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.95
100	3.94	3.09	2.70	2.46	2.31	2.19	2.10	2.03	1.97	1.93	1.89

Continued

F* distribution $F_{0.05}$ *(continued)

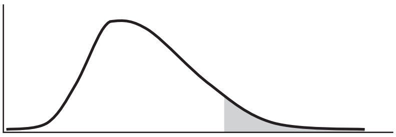
	Numerator degrees of freedom										
Denominator degrees of freedom	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1	243.9	244.7	245.4	245.9	246.5	246.9	247.3	247.7	248.0	248.3	248.6
2	19.41	19.42	19.42	19.43	19.43	19.44	19.44	19.44	19.45	19.45	19.45
3	8.74	8.73	8.71	8.70	8.69	8.68	8.67	8.67	8.66	8.65	8.65
4	5.91	5.89	5.87	5.86	5.84	5.83	5.82	5.81	5.80	5.79	5.79
5	4.68	4.66	4.64	4.62	4.60	4.59	4.58	4.57	4.56	4.55	4.54
6	4.00	3.98	3.96	3.94	3.92	3.91	3.90	3.88	3.87	3.86	3.86
7	3.57	3.55	3.53	3.51	3.49	3.48	3.47	3.46	3.44	3.43	3.43
8	3.28	3.26	3.24	3.22	3.20	3.19	3.17	3.16	3.15	3.14	3.13
9	3.07	3.05	3.03	3.01	2.99	2.97	2.96	2.95	2.94	2.93	2.92
10	2.91	2.89	2.86	2.85	2.83	2.81	2.80	2.79	2.77	2.76	2.75
11	2.79	2.76	2.74	2.72	2.70	2.69	2.67	2.66	2.65	2.64	2.63
12	2.69	2.66	2.64	2.62	2.60	2.58	2.57	2.56	2.54	2.53	2.52
13	2.60	2.58	2.55	2.53	2.51	2.50	2.48	2.47	2.46	2.45	2.44
14	2.53	2.51	2.48	2.46	2.44	2.43	2.41	2.40	2.39	2.38	2.37
15	2.48	2.45	2.42	2.40	2.38	2.37	2.35	2.34	2.33	2.32	2.31
16	2.42	2.40	2.37	2.35	2.33	2.32	2.30	2.29	2.28	2.26	2.25
17	2.38	2.35	2.33	2.31	2.29	2.27	2.26	2.24	2.23	2.22	2.21
18	2.34	2.31	2.29	2.27	2.25	2.23	2.22	2.20	2.19	2.18	2.17
19	2.31	2.28	2.26	2.23	2.21	2.20	2.18	2.17	2.16	2.14	2.13
20	2.28	2.25	2.22	2.20	2.18	2.17	2.15	2.14	2.12	2.11	2.10
21	2.25	2.22	2.20	2.18	2.16	2.14	2.12	2.11	2.10	2.08	2.07
22	2.23	2.20	2.17	2.15	2.13	2.11	2.10	2.08	2.07	2.06	2.05
23	2.20	2.18	2.15	2.13	2.11	2.09	2.08	2.06	2.05	2.04	2.02
24	2.18	2.15	2.13	2.11	2.09	2.07	2.05	2.04	2.03	2.01	2.00
25	2.16	2.14	2.11	2.09	2.07	2.05	2.04	2.02	2.01	2.00	1.98
26	2.15	2.12	2.09	2.07	2.05	2.03	2.02	2.00	1.99	1.98	1.97
27	2.13	2.10	2.08	2.06	2.04	2.02	2.00	1.99	1.97	1.96	1.95
28	2.12	2.09	2.06	2.04	2.02	2.00	1.99	1.97	1.96	1.95	1.93
29	2.10	2.08	2.05	2.03	2.01	1.99	1.97	1.96	1.94	1.93	1.92
30	2.09	2.06	2.04	2.01	1.99	1.98	1.96	1.95	1.93	1.92	1.91
40	2.00	1.97	1.95	1.92	1.90	1.89	1.87	1.85	1.84	1.83	1.81
60	1.92	1.89	1.86	1.84	1.82	1.80	1.78	1.76	1.75	1.73	1.72
100	1.85	1.82	1.79	1.77	1.75	1.73	1.71	1.69	1.68	1.66	1.65

Continued

F distribution $F_{0.05}$ *(continued)*

		Numerator degrees of freedom										
		23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**40**	**60**	**100**
Denominator degrees of freedom	**1**	248.8	249.1	249.3	249.5	249.6	249.8	250.0	250.1	251.1	252.2	253.0
	2	19.45	19.45	19.46	19.46	19.46	19.46	19.46	19.46	19.47	19.48	19.49
	3	8.64	8.64	8.63	8.63	8.63	8.62	8.62	8.62	8.59	8.57	8.55
	4	5.78	5.77	5.77	5.76	5.76	5.75	5.75	5.75	5.72	5.69	5.66
	5	4.53	4.53	4.52	4.52	4.51	4.50	4.50	4.50	4.46	4.43	4.41
	6	3.85	3.84	3.83	3.83	3.82	3.82	3.81	3.81	3.77	3.74	3.71
	7	3.42	3.41	3.40	3.40	3.39	3.39	3.38	3.38	3.34	3.30	3.27
	8	3.12	3.12	3.11	3.10	3.10	3.09	3.08	3.08	3.04	3.01	2.97
	9	2.91	2.90	2.89	2.89	2.88	2.87	2.87	2.86	2.83	2.79	2.76
	10	2.75	2.74	2.73	2.72	2.72	2.71	2.70	2.70	2.66	2.62	2.59
	11	2.62	2.61	2.60	2.59	2.59	2.58	2.58	2.57	2.53	2.49	2.46
	12	2.51	2.51	2.50	2.49	2.48	2.48	2.47	2.47	2.43	2.38	2.35
	13	2.43	2.42	2.41	2.41	2.40	2.39	2.39	2.38	2.34	2.30	2.26
	14	2.36	2.35	2.34	2.33	2.33	2.32	2.31	2.31	2.27	2.22	2.19
	15	2.30	2.29	2.28	2.27	2.27	2.26	2.25	2.25	2.20	2.16	2.12
	16	2.24	2.24	2.23	2.22	2.21	2.21	2.20	2.19	2.15	2.11	2.07
	17	2.20	2.19	2.18	2.17	2.17	2.16	2.15	2.15	2.10	2.06	2.02
	18	2.16	2.15	2.14	2.13	2.13	2.12	2.11	2.11	2.06	2.02	1.98
	19	2.12	2.11	2.11	2.10	2.09	2.08	2.08	2.07	2.03	1.98	1.94
	20	2.09	2.08	2.07	2.07	2.06	2.05	2.05	2.04	1.99	1.95	1.91
	21	2.06	2.05	2.05	2.04	2.03	2.02	2.02	2.01	1.96	1.92	1.88
	22	2.04	2.03	2.02	2.01	2.00	2.00	1.99	1.98	1.94	1.89	1.85
	23	2.01	2.01	2.00	1.99	1.98	1.97	1.97	1.96	1.91	1.86	1.82
	24	1.99	1.98	1.97	1.97	1.96	1.95	1.95	1.94	1.89	1.84	1.80
	25	1.97	1.96	1.96	1.95	1.94	1.93	1.93	1.92	1.87	1.82	1.78
	26	1.96	1.95	1.94	1.93	1.92	1.91	1.91	1.90	1.85	1.80	1.76
	27	1.94	1.93	1.92	1.91	1.90	1.90	1.89	1.88	1.84	1.79	1.74
	28	1.92	1.91	1.91	1.90	1.89	1.88	1.88	1.87	1.82	1.77	1.73
	29	1.91	1.90	1.89	1.88	1.88	1.87	1.86	1.85	1.81	1.75	1.71
	30	1.90	1.89	1.88	1.87	1.86	1.85	1.85	1.84	1.79	1.74	1.70
	40	1.80	1.79	1.78	1.77	1.77	1.76	1.75	1.74	1.69	1.64	1.59
	60	1.71	1.70	1.69	1.68	1.67	1.66	1.66	1.65	1.59	1.53	1.48
	100	1.64	1.63	1.62	1.61	1.60	1.59	1.58	1.57	1.52	1.45	1.39

$F_{0.01}$



***F* distribution $F_{0.01}$**

Denominator degrees of freedom	Numerator degrees of freedom										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	4052	4999	5404	5624	5764	5859	5928	5981	6022	6056	6083
2	98.5	99	99.16	99.25	99.3	99.33	99.36	99.38	99.39	99.4	99.41
3	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.34	27.23	27.13
4	21.2	18	16.69	15.98	15.52	15.21	14.98	14.8	14.66	14.55	14.45
5	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16	10.05	9.963
6	13.75	10.92	9.78	9.148	8.746	8.466	8.26	8.102	7.976	7.874	7.79
7	12.25	9.547	8.451	7.847	7.46	7.191	6.993	6.84	6.719	6.62	6.538
8	11.26	8.649	7.591	7.006	6.632	6.371	6.178	6.029	5.911	5.814	5.734
9	10.56	8.022	6.992	6.422	6.057	5.802	5.613	5.467	5.351	5.257	5.178
10	10.04	7.559	6.552	5.994	5.636	5.386	5.2	5.057	4.942	4.849	4.772
11	9.646	7.206	6.217	5.668	5.316	5.069	4.886	4.744	4.632	4.539	4.462
12	9.33	6.927	5.953	5.412	5.064	4.821	4.64	4.499	4.388	4.296	4.22
13	9.074	6.701	5.739	5.205	4.862	4.62	4.441	4.302	4.191	4.1	4.025
14	8.862	6.515	5.564	5.035	4.695	4.456	4.278	4.14	4.03	3.939	3.864
15	8.683	6.359	5.417	4.893	4.556	4.318	4.142	4.004	3.895	3.805	3.73
16	8.531	6.226	5.292	4.773	4.437	4.202	4.026	3.89	3.78	3.691	3.616
17	8.4	6.112	5.185	4.669	4.336	4.101	3.927	3.791	3.682	3.593	3.518
18	8.285	6.013	5.092	4.579	4.248	4.015	3.841	3.705	3.597	3.508	3.434
19	8.185	5.926	5.01	4.5	4.171	3.939	3.765	3.631	3.523	3.434	3.36
20	8.096	5.849	4.938	4.431	4.103	3.871	3.699	3.564	3.457	3.368	3.294
21	8.017	5.78	4.874	4.369	4.042	3.812	3.64	3.506	3.398	3.31	3.236
22	7.945	5.719	4.817	4.313	3.988	3.758	3.587	3.453	3.346	3.258	3.184
23	7.881	5.664	4.765	4.264	3.939	3.71	3.539	3.406	3.299	3.211	3.137
24	7.823	5.614	4.718	4.218	3.895	3.667	3.496	3.363	3.256	3.168	3.094
25	7.77	5.568	4.675	4.177	3.855	3.627	3.457	3.324	3.217	3.129	3.056
26	7.721	5.526	4.637	4.14	3.818	3.591	3.421	3.288	3.182	3.094	3.021
27	7.677	5.488	4.601	4.106	3.785	3.558	3.388	3.256	3.149	3.062	2.988
28	7.636	5.453	4.568	4.074	3.754	3.528	3.358	3.226	3.12	3.032	2.959
29	7.598	5.42	4.538	4.045	3.725	3.499	3.33	3.198	3.092	3.005	2.931
30	7.562	5.39	4.51	4.018	3.699	3.473	3.305	3.173	3.067	2.979	2.906
40	7.314	5.178	4.313	3.828	3.514	3.291	3.124	2.993	2.888	2.801	2.727
60	7.077	4.977	4.126	3.649	3.339	3.119	2.953	2.823	2.718	2.632	2.559
100	6.895	4.824	3.984	3.513	3.206	2.988	2.823	2.694	2.59	2.503	2.43

Continued

F distribution $F_{0.01}$ *(continued)*

	Numerator degrees of freedom										
Denominator degrees of freedom	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1	6107	6126	6143	6157	6170	6181	6191	6201	6208.7	6216.1	6223.1
2	99.42	99.42	99.43	99.43	99.44	99.44	99.44	99.45	99.448	99.451	99.455
3	27.05	26.98	26.92	26.87	26.83	26.79	26.75	26.72	26.69	26.664	26.639
4	14.37	14.31	14.25	14.2	14.15	14.11	14.08	14.05	14.019	13.994	13.97
5	9.888	9.825	9.77	9.722	9.68	9.643	9.609	9.58	9.5527	9.5281	9.5058
6	7.718	7.657	7.605	7.559	7.519	7.483	7.451	7.422	7.3958	7.3721	7.3506
7	6.469	6.41	6.359	6.314	6.275	6.24	6.209	6.181	6.1555	6.1324	6.1113
8	5.667	5.609	5.559	5.515	5.477	5.442	5.412	5.384	5.3591	5.3365	5.3157
9	5.111	5.055	5.005	4.962	4.924	4.89	4.86	4.833	4.808	4.7855	4.7651
10	4.706	4.65	4.601	4.558	4.52	4.487	4.457	4.43	4.4054	4.3831	4.3628
11	4.397	4.342	4.293	4.251	4.213	4.18	4.15	4.123	4.099	4.0769	4.0566
12	4.155	4.1	4.052	4.01	3.972	3.939	3.91	3.883	3.8584	3.8363	3.8161
13	3.96	3.905	3.857	3.815	3.778	3.745	3.716	3.689	3.6646	3.6425	3.6223
14	3.8	3.745	3.698	3.656	3.619	3.586	3.556	3.529	3.5052	3.4832	3.463
15	3.666	3.612	3.564	3.522	3.485	3.452	3.423	3.396	3.3719	3.3498	3.3297
16	3.553	3.498	3.451	3.409	3.372	3.339	3.31	3.283	3.2587	3.2367	3.2165
17	3.455	3.401	3.353	3.312	3.275	3.242	3.212	3.186	3.1615	3.1394	3.1192
18	3.371	3.316	3.269	3.227	3.19	3.158	3.128	3.101	3.0771	3.055	3.0348
19	3.297	3.242	3.195	3.153	3.116	3.084	3.054	3.027	3.0031	2.981	2.9607
20	3.231	3.177	3.13	3.088	3.051	3.018	2.989	2.962	2.9377	2.9156	2.8953
21	3.173	3.119	3.072	3.03	2.993	2.96	2.931	2.904	2.8795	2.8574	2.837
22	3.121	3.067	3.019	2.978	2.941	2.908	2.879	2.852	2.8274	2.8052	2.7849
23	3.074	3.02	2.973	2.931	2.894	2.861	2.832	2.805	2.7805	2.7582	2.7378
24	3.032	2.977	2.93	2.889	2.852	2.819	2.789	2.762	2.738	2.7157	2.6953
25	2.993	2.939	2.892	2.85	2.813	2.78	2.751	2.724	2.6993	2.677	2.6565
26	2.958	2.904	2.857	2.815	2.778	2.745	2.715	2.688	2.664	2.6416	2.6211
27	2.926	2.872	2.824	2.783	2.746	2.713	2.683	2.656	2.6316	2.609	2.5886
28	2.896	2.842	2.795	2.753	2.716	2.683	2.653	2.626	2.6018	2.5793	2.5587
29	2.868	2.814	2.767	2.726	2.689	2.656	2.626	2.599	2.5742	2.5517	2.5311
30	2.843	2.789	2.742	2.7	2.663	2.63	2.6	2.573	2.5487	2.5262	2.5055
40	2.665	2.611	2.563	2.522	2.484	2.451	2.421	2.394	2.3689	2.3461	2.3252
60	2.496	2.442	2.394	2.352	2.315	2.281	2.251	2.223	2.1978	2.1747	2.1533
10	2.368	2.313	2.265	2.223	2.185	2.151	2.12	2.092	2.0666	2.0431	2.0214

Continued

F* distribution $F_{0.01}$ *(continued)

	Numerator degrees of freedom										
Denominator degrees of freedom	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**40**	**60**	**100**
1	6228.7	6234.3	6239.9	6244.5	6249.2	6252.9	6257.1	6260.4	6286.4	6313	6333.9
2	99.455	99.455	99.459	99.462	99.462	99.462	99.462	99.466	99.477	99.484	99.491
3	26.617	26.597	26.579	26.562	26.546	26.531	26.517	26.504	26.411	26.316	26.241
4	13.949	13.929	13.911	13.894	13.878	13.864	13.85	13.838	13.745	13.652	13.577
5	9.4853	9.4665	9.4492	9.4331	9.4183	9.4044	9.3914	9.3794	9.2912	9.202	9.13
6	7.3309	7.3128	7.296	7.2805	7.2661	7.2528	7.2403	7.2286	7.1432	7.0568	6.9867
7	6.092	6.0743	6.0579	6.0428	6.0287	6.0156	6.0035	5.992	5.9084	5.8236	5.7546
8	5.2967	5.2793	5.2631	5.2482	5.2344	5.2214	5.2094	5.1981	5.1156	5.0316	4.9633
9	4.7463	4.729	4.713	4.6982	4.6845	4.6717	4.6598	4.6486	4.5667	4.4831	4.415
10	4.3441	4.3269	4.3111	4.2963	4.2827	4.27	4.2582	4.2469	4.1653	4.0819	4.0137
11	4.038	4.0209	4.0051	3.9904	3.9768	3.9641	3.9522	3.9411	3.8596	3.7761	3.7077
12	3.7976	3.7805	3.7647	3.7501	3.7364	3.7238	3.7119	3.7008	3.6192	3.5355	3.4668
13	3.6038	3.5868	3.571	3.5563	3.5427	3.53	3.5182	3.507	3.4253	3.3413	3.2723
14	3.4445	3.4274	3.4116	3.3969	3.3833	3.3706	3.3587	3.3476	3.2657	3.1813	3.1118
15	3.3111	3.294	3.2782	3.2636	3.2499	3.2372	3.2253	3.2141	3.1319	3.0471	2.9772
16	3.1979	3.1808	3.165	3.1503	3.1366	3.1238	3.1119	3.1007	3.0182	2.933	2.8627
17	3.1006	3.0835	3.0676	3.0529	3.0392	3.0264	3.0145	3.0032	2.9204	2.8348	2.7639
18	3.0161	2.999	2.9831	2.9683	2.9546	2.9418	2.9298	2.9185	2.8354	2.7493	2.6779
19	2.9421	2.9249	2.9089	2.8942	2.8804	2.8675	2.8555	2.8442	2.7608	2.6742	2.6023
20	2.8766	2.8594	2.8434	2.8286	2.8148	2.8019	2.7898	2.7785	2.6947	2.6077	2.5353
21	2.8183	2.801	2.785	2.7702	2.7563	2.7434	2.7313	2.72	2.6359	2.5484	2.4755
22	2.7661	2.7488	2.7328	2.7179	2.704	2.691	2.6789	2.6675	2.5831	2.4951	2.4218
23	2.7191	2.7017	2.6857	2.6707	2.6568	2.6438	2.6316	2.6202	2.5355	2.4471	2.3732
24	2.6764	2.6591	2.643	2.628	2.614	2.601	2.5888	2.5773	2.4923	2.4035	2.3291
25	2.6377	2.6203	2.6041	2.5891	2.5751	2.562	2.5498	2.5383	2.453	2.3637	2.2888
26	2.6022	2.5848	2.5686	2.5535	2.5395	2.5264	2.5142	2.5026	2.417	2.3273	2.2519
27	2.5697	2.5522	2.536	2.5209	2.5069	2.4937	2.4814	2.4699	2.384	2.2938	2.218
28	2.5398	2.5223	2.506	2.4909	2.4768	2.4636	2.4513	2.4397	2.3535	2.2629	2.1867
29	2.5121	2.4946	2.4783	2.4631	2.449	2.4358	2.4234	2.4118	2.3253	2.2344	2.1577
30	2.4865	2.4689	2.4526	2.4374	2.4233	2.41	2.3976	2.386	2.2992	2.2079	2.1307
40	2.3059	2.288	2.2714	2.2559	2.2415	2.228	2.2153	2.2034	2.1142	2.0194	1.9383
60	2.1336	2.1154	2.0984	2.0825	2.0677	2.0538	2.0408	2.0285	1.936	1.8363	1.7493
100	2.0012	1.9826	1.9651	1.9489	1.9337	1.9194	1.9059	1.8933	1.7972	1.6918	1.5977

Appendix H

Binomial Distribution

Probability of *x* or fewer occurrences in a sample of size *n*

Binomial distribution

		p																	
n	***x***	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**
2	**0**	0.980	0.960	0.941	0.922	0.903	0.884	0.865	0.846	0.828	0.810	0.723	0.640	0.563	0.490	0.423	0.360	0.303	0.250
2	**1**	1.000	1.000	0.999	0.998	0.998	0.996	0.995	0.994	0.992	0.990	0.978	0.960	0.938	0.910	0.878	0.840	0.798	0.750
3	**0**	0.970	0.941	0.913	0.885	0.857	0.831	0.804	0.779	0.754	0.729	0.614	0.512	0.422	0.343	0.275	0.216	0.166	0.125
3	**1**	1.000	0.999	0.997	0.995	0.993	0.990	0.986	0.982	0.977	0.972	0.939	0.896	0.844	0.784	0.718	0.648	0.575	0.500
3	**2**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.999	0.999	0.997	0.992	0.984	0.973	0.957	0.936	0.909	0.875
4	**0**	0.961	0.922	0.885	0.849	0.815	0.781	0.748	0.716	0.686	0.656	0.522	0.410	0.316	0.240	0.179	0.130	0.092	0.063
4	**1**	0.999	0.998	0.995	0.991	0.986	0.980	0.973	0.966	0.957	0.948	0.890	0.819	0.738	0.652	0.563	0.475	0.391	0.313
4	**2**	1.000	1.000	1.000	1.000	1.000	0.999	0.999	0.998	0.997	0.996	0.988	0.973	0.949	0.916	0.874	0.821	0.759	0.688
4	**3**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.998	0.996	0.992	0.985	0.974	0.959	0.938
5	**0**	0.951	0.904	0.859	0.815	0.774	0.734	0.696	0.659	0.624	0.590	0.444	0.328	0.237	0.168	0.116	0.078	0.050	0.031
5	**1**	0.999	0.996	0.992	0.985	0.977	0.968	0.958	0.946	0.933	0.919	0.835	0.737	0.633	0.528	0.428	0.337	0.256	0.188
5	**2**	1.000	1.000	1.000	0.999	0.999	0.998	0.997	0.995	0.994	0.991	0.973	0.942	0.896	0.837	0.765	0.683	0.593	0.500
5	**3**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.998	0.993	0.984	0.969	0.946	0.913	0.869	0.813
5	**4**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.998	0.995	0.990	0.982	0.969
6	**0**	0.941	0.886	0.833	0.783	0.735	0.690	0.647	0.606	0.568	0.531	0.377	0.262	0.178	0.118	0.075	0.047	0.028	0.016
6	**1**	0.999	0.994	0.988	0.978	0.967	0.954	0.939	0.923	0.905	0.886	0.776	0.655	0.534	0.420	0.319	0.233	0.164	0.109
6	**2**	1.000	1.000	0.999	0.999	0.998	0.996	0.994	0.991	0.988	0.984	0.953	0.901	0.831	0.744	0.647	0.544	0.442	0.344
6	**3**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.999	0.999	0.994	0.983	0.962	0.930	0.883	0.821	0.745	0.656
6	**4**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.998	0.995	0.989	0.978	0.959	0.931	0.891
6	**5**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.998	0.996	0.992	0.984
7	**0**	0.932	0.868	0.808	0.751	0.698	0.648	0.602	0.558	0.517	0.478	0.321	0.210	0.133	0.082	0.049	0.028	0.015	0.008
7	**1**	0.998	0.992	0.983	0.971	0.956	0.938	0.919	0.897	0.875	0.850	0.717	0.577	0.445	0.329	0.234	0.159	0.102	0.063
7	**2**	1.000	1.000	0.999	0.998	0.996	0.994	0.990	0.986	0.981	0.974	0.926	0.852	0.756	0.647	0.532	0.420	0.316	0.227
7	**3**	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.999	0.998	0.997	0.988	0.967	0.929	0.874	0.800	0.710	0.608	0.500
7	**4**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.995	0.987	0.971	0.944	0.904	0.847	0.773
7	**5**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.996	0.991	0.981	0.964	0.938
7	**6**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.998	0.996	0.992

Continued

Binomial distribution *(continued)*

		p																	
n	*x*	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**
8	**0**	0.923	0.851	0.784	0.721	0.663	0.610	0.560	0.513	0.470	0.430	0.272	0.168	0.100	0.058	0.032	0.017	0.008	0.004
8	**1**	0.997	0.990	0.978	0.962	0.943	0.921	0.897	0.870	0.842	0.813	0.657	0.503	0.367	0.255	0.169	0.106	0.063	0.035
8	**2**	1.000	1.000	0.999	0.997	0.994	0.990	0.985	0.979	0.971	0.962	0.895	0.797	0.679	0.552	0.428	0.315	0.220	0.145
8	**3**	1.000	1.000	1.000	1.000	1.000	0.999	0.999	0.998	0.997	0.995	0.979	0.944	0.886	0.806	0.706	0.594	0.477	0.363
8	**4**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.997	0.990	0.973	0.942	0.894	0.826	0.740	0.637
8	**5**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.996	0.989	0.975	0.950	0.912	0.855
8	**6**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.996	0.991	0.982	0.965
8	**7**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.998	0.996
9	**0**	0.914	0.834	0.760	0.693	0.630	0.573	0.520	0.472	0.428	0.387	0.232	0.134	0.075	0.040	0.021	0.010	0.005	0.002
9	**1**	0.997	0.987	0.972	0.952	0.929	0.902	0.873	0.842	0.809	0.775	0.599	0.436	0.300	0.196	0.121	0.071	0.039	0.020
9	**2**	1.000	0.999	0.998	0.996	0.992	0.986	0.979	0.970	0.960	0.947	0.859	0.738	0.601	0.463	0.337	0.232	0.150	0.090
9	**3**	1.000	1.000	1.000	1.000	0.999	0.999	0.998	0.996	0.994	0.992	0.966	0.914	0.834	0.730	0.609	0.483	0.361	0.254
9	**4**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.999	0.994	0.980	0.951	0.901	0.828	0.733	0.621	0.500
9	**5**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.997	0.990	0.975	0.946	0.901	0.834	0.746
9	**6**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.996	0.989	0.975	0.950	0.910
9	**7**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.996	0.991	0.980
9	**8**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.998
10	**0**	0.904	0.817	0.737	0.665	0.599	0.539	0.484	0.434	0.389	0.349	0.197	0.107	0.056	0.028	0.013	0.006	0.003	0.001
10	**1**	0.996	0.984	0.965	0.942	0.914	0.882	0.848	0.812	0.775	0.736	0.544	0.376	0.244	0.149	0.086	0.046	0.023	0.011
10	**2**	1.000	0.999	0.997	0.994	0.988	0.981	0.972	0.960	0.946	0.930	0.820	0.678	0.526	0.383	0.262	0.167	0.100	0.055
10	**3**	1.000	1.000	1.000	1.000	0.999	0.998	0.996	0.994	0.991	0.987	0.950	0.879	0.776	0.650	0.514	0.382	0.266	0.172
10	**4**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.999	0.998	0.990	0.967	0.922	0.850	0.751	0.633	0.504	0.377
10	**5**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.994	0.980	0.953	0.905	0.834	0.738	0.623

Appendix I

Chi-Square Distribution

Chi-square distribution

df	$\chi^2_{0.995}$	$\chi^2_{0.99}$	$\chi^2_{0.975}$	$\chi^2_{0.95}$	$\chi^2_{0.90}$	$\chi^2_{0.10}$	$\chi^2_{0.05}$	$\chi^2_{0.025}$	$\chi^2_{0.01}$	$\chi^2_{0.005}$
1	0.000	0.000	0.001	0.004	0.016	2.706	3.841	5.024	6.635	7.879
2	0.010	0.020	0.051	0.103	0.211	4.605	5.991	7.378	9.210	10.597
3	0.072	0.115	0.216	0.352	0.584	6.251	7.815	9.348	11.345	12.838
4	0.207	0.297	0.484	0.711	1.064	7.779	9.488	11.143	13.277	14.860
5	0.412	0.554	0.831	1.145	1.610	9.236	11.070	12.832	15.086	16.750
6	0.676	0.872	1.237	1.635	2.204	10.645	12.592	14.449	16.812	18.548
7	0.989	1.239	1.690	2.167	2.833	12.017	14.067	16.013	18.475	20.278
8	1.344	1.647	2.180	2.733	3.490	13.362	15.507	17.535	20.090	21.955
9	1.735	2.088	2.700	3.325	4.168	14.684	16.919	19.023	21.666	23.589
10	2.156	2.558	3.247	3.940	4.865	15.987	18.307	20.483	23.209	25.188
11	2.603	3.053	3.816	4.575	5.578	17.275	19.675	21.920	24.725	26.757
12	3.074	3.571	4.404	5.226	6.304	18.549	21.026	23.337	26.217	28.300
13	3.565	4.107	5.009	5.892	7.041	19.812	22.362	24.736	27.688	29.819
14	4.075	4.660	5.629	6.571	7.790	21.064	23.685	26.119	29.141	31.319
15	4.601	5.229	6.262	7.261	8.547	22.307	24.996	27.488	30.578	32.801
16	5.142	5.812	6.908	7.962	9.312	23.542	26.296	28.845	32.000	34.267
17	5.697	6.408	7.564	8.672	10.085	24.769	27.587	30.191	33.409	35.718
18	6.265	7.015	8.231	9.390	10.865	25.989	28.869	31.526	34.805	37.156
19	6.844	7.633	8.907	10.117	11.651	27.204	30.144	32.852	36.191	38.582
20	7.434	8.260	9.591	10.851	12.443	28.412	31.410	34.170	37.566	39.997
21	8.034	8.897	10.283	11.591	13.240	29.615	32.671	35.479	38.932	41.401
22	8.643	9.542	10.982	12.338	14.041	30.813	33.924	36.781	40.289	42.796
23	9.260	10.196	11.689	13.091	14.848	32.007	35.172	38.076	41.638	44.181
24	9.886	10.856	12.401	13.848	15.659	33.196	36.415	39.364	42.980	45.558
25	10.520	11.524	13.120	14.611	16.473	34.382	37.652	40.646	44.314	46.928
26	11.160	12.198	13.844	15.379	17.292	35.563	38.885	41.923	45.642	48.290
27	11.808	12.878	14.573	16.151	18.114	36.741	40.113	43.195	46.963	49.645
28	12.461	13.565	15.308	16.928	18.939	37.916	41.337	44.461	48.278	50.994

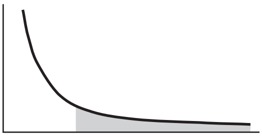
Continued

Chi-square distribution *(continued)*

df	$\chi^2_{0.995}$	$\chi^2_{0.99}$	$\chi^2_{0.975}$	$\chi^2_{0.95}$	$\chi^2_{0.90}$	$\chi^2_{0.10}$	$\chi^2_{0.05}$	$\chi^2_{0.025}$	$\chi^2_{0.01}$	$\chi^2_{0.005}$
29	13.121	14.256	16.047	17.708	19.768	39.087	42.557	45.722	49.588	52.335
30	13.787	14.953	16.791	18.493	20.599	40.256	43.773	46.979	50.892	53.672
31	14.458	15.655	17.539	19.281	21.434	41.422	44.985	48.232	52.191	55.002
32	15.134	16.362	18.291	20.072	22.271	42.585	46.194	49.480	53.486	56.328
33	15.815	17.073	19.047	20.867	23.110	43.745	47.400	50.725	54.775	57.648
34	16.501	17.789	19.806	21.664	23.952	44.903	48.602	51.966	56.061	58.964
35	17.192	18.509	20.569	22.465	24.797	46.059	49.802	53.203	57.342	60.275
40	20.707	22.164	24.433	26.509	29.051	51.805	55.758	59.342	63.691	66.766
45	24.311	25.901	28.366	30.612	33.350	57.505	61.656	65.410	69.957	73.166
50	27.991	29.707	32.357	34.764	37.689	63.167	67.505	71.420	76.154	79.490
55	31.735	33.571	36.398	38.958	42.060	68.796	73.311	77.380	82.292	85.749
60	35.534	37.485	40.482	43.188	46.459	74.397	79.082	83.298	88.379	91.952
65	39.383	41.444	44.603	47.450	50.883	79.973	84.821	89.177	94.422	98.105
70	43.275	45.442	48.758	51.739	55.329	85.527	90.531	95.023	100.425	104.215
75	47.206	49.475	52.942	56.054	59.795	91.061	96.217	100.839	106.393	110.285
80	51.172	53.540	57.153	60.391	64.278	96.578	101.879	106.629	112.329	116.321
85	55.170	57.634	61.389	64.749	68.777	102.079	107.522	112.393	118.236	122.324
90	59.196	61.754	65.647	69.126	73.291	107.565	113.145	118.136	124.116	128.299
95	63.250	65.898	69.925	73.520	77.818	113.038	118.752	123.858	129.973	134.247
100	67.328	70.065	74.222	77.929	82.358	118.498	124.342	129.561	135.807	140.170

Appendix J

Exponential Distribution



Exponential distribution

X	Area to left of *X*	Area to right of *X*
0	0.00000	1.00000
0.1	0.09516	0.90484
0.2	0.18127	0.81873
0.3	0.25918	0.74082
0.4	0.32968	0.67032
0.5	0.39347	0.60653
0.6	0.45119	0.54881
0.7	0.50341	0.49659
0.8	0.55067	0.44933
0.9	0.59343	0.40657
1	0.63212	0.36788
1.1	0.66713	0.33287
1.2	0.69881	0.30119
1.3	0.72747	0.27253
1.4	0.75340	0.24660
1.5	0.77687	0.22313
1.6	0.79810	0.20190
1.7	0.81732	0.18268
1.8	0.83470	0.16530
1.9	0.85043	0.14957
2	0.86466	0.13534
2.1	0.87754	0.12246
2.2	0.88920	0.11080
2.3	0.89974	0.10026
2.4	0.90928	0.09072
2.5	0.91792	0.08208
2.6	0.92573	0.07427

Continued

Exponential distribution *(continued)*

X	Area to left of *X*	Area to right of *X*
2.7	0.93279	0.06721
2.8	0.93919	0.06081
2.9	0.94498	0.05502
3	0.95021	0.04979
3.1	0.95495	0.04505
3.2	0.95924	0.04076
3.3	0.96312	0.03688
3.4	0.96663	0.03337
3.5	0.96980	0.03020
3.6	0.97268	0.02732
3.7	0.97528	0.02472
3.8	0.97763	0.02237
3.9	0.97976	0.02024
4	0.98168	0.01832
4.1	0.98343	0.01657
4.2	0.98500	0.01500
4.3	0.98643	0.01357
4.4	0.98772	0.01228
4.5	0.98889	0.01111
4.6	0.98995	0.01005
4.7	0.99090	0.00910
4.8	0.99177	0.00823
4.9	0.99255	0.00745
5	0.99326	0.00674
5.1	0.99390	0.00610
5.2	0.99448	0.00552
5.3	0.99501	0.00499
5.4	0.99548	0.00452
5.5	0.99591	0.00409
5.6	0.99630	0.00370
5.7	0.99665	0.00335
5.8	0.99697	0.00303
5.9	0.99726	0.00274
6	0.99752	0.00248

Appendix K

Poisson Distribution

Probability of *x* or fewer occurrences of an event

Poisson distribution

$\lambda\downarrow$ $x\rightarrow$	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0.005	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.01	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.02	0.980	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.03	0.970	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.04	0.961	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.05	0.951	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.06	0.942	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.07	0.932	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.08	0.923	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.09	0.914	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.1	0.905	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.15	0.861	0.990	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.2	0.819	0.982	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.25	0.779	0.974	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.3	0.741	0.963	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.35	0.705	0.951	0.994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.4	0.670	0.938	0.992	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.5	0.607	0.910	0.986	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.6	0.549	0.878	0.977	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.7	0.497	0.844	0.966	0.994	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.8	0.449	0.809	0.953	0.991	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.9	0.407	0.772	0.937	0.987	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	0.368	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1.2	0.301	0.663	0.879	0.966	0.992	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1.4	0.247	0.592	0.833	0.946	0.986	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1.6	0.202	0.525	0.783	0.921	0.976	0.994	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1.8	0.165	0.463	0.731	0.891	0.964	0.990	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.135	0.406	0.677	0.857	0.947	0.983	0.995	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

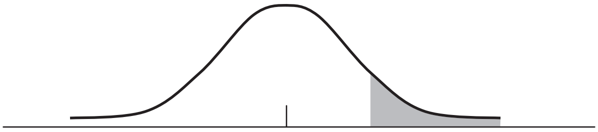
Continued

Poisson distribution *(continued)*

$\lambda\downarrow$ $x\rightarrow$	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
2.2	0.111	0.355	0.623	0.819	0.928	0.975	0.993	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2.4	0.091	0.308	0.570	0.779	0.904	0.964	0.988	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2.6	0.074	0.267	0.518	0.736	0.877	0.951	0.983	0.995	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2.8	0.061	0.231	0.469	0.692	0.848	0.935	0.976	0.992	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	0.050	0.199	0.423	0.647	0.815	0.916	0.966	0.988	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3.2	0.041	0.171	0.380	0.603	0.781	0.895	0.955	0.983	0.994	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3.4	0.033	0.147	0.340	0.558	0.744	0.871	0.942	0.977	0.992	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3.6	0.027	0.126	0.303	0.515	0.706	0.844	0.927	0.969	0.988	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3.8	0.022	0.107	0.269	0.473	0.668	0.816	0.909	0.960	0.984	0.994	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000
4	0.018	0.092	0.238	0.433	0.629	0.785	0.889	0.949	0.979	0.992	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000
4.5	0.011	0.061	0.174	0.342	0.532	0.703	0.831	0.913	0.960	0.983	0.993	0.998	0.999	1.000	1.000	1.000	1.000	1.000
5	0.007	0.040	0.125	0.265	0.440	0.616	0.762	0.867	0.932	0.968	0.986	0.995	0.998	0.999	1.000	1.000	1.000	1.000
5.5	0.004	0.027	0.088	0.202	0.358	0.529	0.686	0.809	0.894	0.946	0.975	0.989	0.996	0.998	0.999	1.000	1.000	1.000
6	0.002	0.017	0.062	0.151	0.285	0.446	0.606	0.744	0.847	0.916	0.957	0.980	0.991	0.996	0.999	0.999	1.000	1.000
6.5	0.002	0.011	0.043	0.112	0.224	0.369	0.527	0.673	0.792	0.877	0.933	0.966	0.984	0.993	0.997	0.999	1.000	1.000
7	0.001	0.007	0.030	0.082	0.173	0.301	0.450	0.599	0.729	0.830	0.901	0.947	0.973	0.987	0.994	0.998	0.999	1.000
7.5	0.001	0.005	0.020	0.059	0.132	0.241	0.378	0.525	0.662	0.776	0.862	0.921	0.957	0.978	0.990	0.995	0.998	0.999
8	0.000	0.003	0.014	0.042	0.100	0.191	0.313	0.453	0.593	0.717	0.816	0.888	0.936	0.966	0.983	0.992	0.996	0.998
8.5	0.000	0.002	0.009	0.030	0.074	0.150	0.256	0.386	0.523	0.653	0.763	0.849	0.909	0.949	0.973	0.986	0.993	0.997
9	0.000	0.001	0.006	0.021	0.055	0.116	0.207	0.324	0.456	0.587	0.706	0.803	0.876	0.926	0.959	0.978	0.989	0.995
9.5	0.000	0.001	0.004	0.015	0.040	0.089	0.165	0.269	0.392	0.522	0.645	0.752	0.836	0.898	0.940	0.967	0.982	0.991
10	0.000	0.000	0.003	0.010	0.029	0.067	0.130	0.220	0.333	0.458	0.583	0.697	0.792	0.864	0.917	0.951	0.973	0.986
10.5	0.000	0.000	0.002	0.007	0.021	0.050	0.102	0.179	0.279	0.397	0.521	0.639	0.742	0.825	0.888	0.932	0.960	0.978

Appendix L

Values of the *t*-Distribution



Values of *t* distribution

ν	$t_{0.100}$	$t_{0.050}$	$t_{0.025}$	$t_{0.010}$	$t_{0.005}$	ν
1	3.078	6.314	12.706	31.821	63.656	1
2	1.886	2.920	4.303	6.965	9.925	2
3	1.638	2.353	3.182	4.541	5.841	3
4	1.533	2.132	2.776	3.747	4.604	4
5	1.476	2.015	2.571	3.365	4.032	5
6	1.440	1.943	2.447	3.143	3.707	6
7	1.415	1.895	2.365	2.998	3.499	7
8	1.397	1.860	2.306	2.896	3.355	8
9	1.383	1.833	2.262	2.821	3.250	9
10	1.372	1.812	2.228	2.764	3.169	10
11	1.363	1.796	2.201	2.718	3.106	11
12	1.356	1.782	2.179	2.681	3.055	12
13	1.350	1.771	2.160	2.650	3.012	13
14	1.345	1.761	2.145	2.624	2.977	14
15	1.341	1.753	2.131	2.602	2.947	15
16	1.337	1.746	2.120	2.583	2.921	16
17	1.333	1.740	2.110	2.567	2.898	17
18	1.330	1.734	2.101	2.552	2.878	18
19	1.328	1.729	2.093	2.539	2.861	19
20	1.325	1.725	2.086	2.528	2.845	20
21	1.323	1.721	2.080	2.518	2.831	21
22	1.321	1.717	2.074	2.508	2.819	22
23	1.319	1.714	2.069	2.500	2.807	23
24	1.318	1.711	2.064	2.492	2.797	24
25	1.316	1.708	2.060	2.485	2.787	25
26	1.315	1.706	2.056	2.479	2.779	26
27	1.314	1.703	2.052	2.473	2.771	27
28	1.313	1.701	2.048	2.467	2.763	28

Continued

Values of *t* distribution *(continued)*

ν	$t_{0.10}$	$t_{0.05}$	$t_{0.025}$	$t_{0.01}$	$t_{0.005}$	ν
29	1.311	1.699	2.045	2.462	2.756	29
30	1.310	1.697	2.042	2.457	2.750	30
31	1.309	1.696	2.040	2.453	2.744	31
32	1.309	1.694	2.037	2.449	2.738	32
33	1.308	1.692	2.035	2.445	2.733	33
34	1.307	1.691	2.032	2.441	2.728	34
35	1.306	1.690	2.030	2.438	2.724	35
40	1.303	1.684	2.021	2.423	2.704	40
45	1.301	1.679	2.014	2.412	2.690	45
50	1.299	1.676	2.009	2.403	2.678	50
55	1.297	1.673	2.004	2.396	2.668	55
60	1.296	1.671	2.000	2.390	2.660	60
70	1.294	1.667	1.994	2.381	2.648	70
80	1.292	1.664	1.990	2.374	2.639	80
90	1.291	1.662	1.987	2.368	2.632	90
100	1.290	1.660	1.984	2.364	2.626	100
200	1.286	1.653	1.972	2.345	2.601	200
400	1.284	1.649	1.966	2.336	2.588	400
600	1.283	1.647	1.964	2.333	2.584	600
800	1.283	1.647	1.963	2.331	2.582	800
999	1.282	1.646	1.962	2.330	2.581	999

Appendix M

Acronym List

14 Points—Doctor Deming's 14 management practices

3C—cognition, comprehension, commitment

3D—dirty, dangerous, difficult

3P—people, planet, profit

3P—people, product, process

3P—production preparation process

4E—education, enforcement, engineering, environment

5F—find it, focus on it, fast, fix it, feedback

5M&P—materials, methods, machines, measurement, Mother Nature, and people

5P—Honda problem solving approach

5S—sort (seiri), straighten (seiton), shine (seiso), standardize (seiketsu), sustain (shitsuke)

5W1H—what, where, when, why, who, and how

6S—**5S** with *safety* added

7P—proper prior planning prevents piss poor performance

7S—**6S** with *oversight* added

8D—eight disciplines of problem solving

8M—man (people), machine (equipment), methods (operating procedures), materials, measurement, Mother Nature (environment), management, and money

A2LA—American Association for Laboratory Accreditation

A3—executive report on one page

ABET—ABET, Inc. (formerly the Accreditation Board of Education and Training)

AD—Anderson-Darling test

AIDR—aircraft inspection deficiency reports

AHP—analytic hierarchy process

AHT—average handling time

AIAG—Automotive Industry Action Group

AMA—American Management Association

ANAB—American National Accreditation Board

AND—activity network diagram

ANOM—analysis of means

ANOVA—analysis of variance

ANSI—American National Standards Institute

AOQ—average outgoing quality

AOQL—average outgoing quality limit

APQP—advanced product quality planning

AQAP—airspace quality advanced quality

AQL—acceptable quality level

AQP—advanced quality planning

AQP—Association for Quality and Participation (organization is now part of ASQ)

AQS—advanced quality system

AQT—acceptable quality test

ARL—average run length

AS—aerospace standards

ASA—American Statistical Association

ASCII—American standard code for information interchange

ASEE—American Society for Engineering Education

ASI—American Supplier Institute

ASME—American Society of Mechanical Engineers

ASN—average sample number

ASNT—American Society for Nondestructive Testing

ASQ—American Society for Quality

ASQC—American Society for Quality Control (ASQ name before 1997)

ASSE—American Society for Safety Engineers

ASTD—American Society for Training and Development

ASTM—ASTM International—formerly American Society for Testing and Materials

AV—appraiser variation

B/I—break in

B2C—business to customer

BAU—business-as-usual

BB—Black Belt

BBS—behavior based safety

BCI—Business Continuity Institute

BCM—business continuity management

BCMS—business continuity management system

BCP—business continuity plan

BCRRA—business continuity resource requirements analysis

BCSP—Board of Certified Safety Professionals

BIA—business impact analysis

BIB—balanced incomplete block design

BIC—best in class

BIC—business improvement coach

BIT—built-in test

BITE—built-in test equipment

BLT-bottom line on top

BOB—best of the best

BoK—body of knowledge

BOM—bill of materials

BOS—business operating system

BPO—best practice organization

BPR—business process reengineering

BRC—British Retail Consortium

BSI—British Standards Institute

BTW—by the way

C&E—cause and effect

C/N—change notice

C/O—changeover time
C/T—cycle time
CAA—Clean Air Act
CAA—compliance assurance agreement
CAD—computer-aided design
CADQAD—computer-aided development of quality assurance data
CAE—computer-aided engineering
CAFÉ—corporate average fuel economy
CAM—computer-aided manufacturing
CAMP—corrective action management process
CANDO—clean up, arranging, neatness, discipline, ongoing improvement
CAP—change acceleration process
CAP—corrective action plan
CAPA—corrective and preventive action
CAQ—computer-aided quality assurance
CAQ—condition adverse to quality
CAR—corrective action recommendation
CAR—corrective action report
CARE—customer acceptance review and evaluation
CASE—computer-aided software engineering
CASE—coordinated aerospace supplier evaluation
CBA—ASQ Certified Biomedical Auditor
CBP—customer benefits package
CBT—computer-based training
CC—critical characteristic
CCR—capacity constraint resource
CCR—critical customer requirement
CCT—ASQ Certified Calibration Technician
CE—cause and effect (for example, CE matrix)
CE—concurrent engineering
CEDAC—cause-and-effect diagram with additional of cards
CEO—chief executive officer

CEPT—Centre (for) Environmental Planning (and) Technology [India]

CERCLA—Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)

CF—controlled forms

CFL—customer first leader

CFO—chief financial officer

CFR—USA Code of Federal Regulations

CGMP—current good manufacturing practice

CHA—ASQ Certified HACCP Auditor

CI—continual improvement

CIA—Certified Internal Auditor

CIM—change-in-mean-effect

CIO—chief information officer

CIP—clean in place

CIPO—continual improvement program owner

CIT—critical items list

CLCA—closed-loop corrective action

Cm—capability machine

CM—condition monitoring

CMI—ASQ Certified Mechanical Inspector

Cmk—machine capability index

CMM—capability maturity model for software (also known as SW-CMM)

CMM—coordinate measuring machine

CMP—crisis management plan

CMQ/OE—ASQ Certified Manager of Quality and Operational Excellence

CMQOE—ASQ Certified Manager of Quality Organizational Excellence

CNC—computer numerical control

COA—certificate of analysis

COB—chairman of board

COB—close of business

COC—certificate of conformance

COC—cost of conformance

COCQ—cost of current quality

CONC—cost of nonconformance

COO—chief operating officer

COP—code of practice

COP—customer oriented process

COPIS—customer, output, process, input, supplier

COPQ—cost of poor quality—measure of waste in operation

COQ—cost of quality (*see* COPQ)

COQC—certificate of quality compliance

CP—control plan

CPR—corrective preventive report

Cp—Process capability measurement—compares engineering specification divided by process six standard deviations

CPD—continuous professional development

Cpk—Process capability measurement—compares engineering specification to process mean divided by three standard deviations

CPM—critical path method

CPN—critical path network

CPU—cost per unit

CQA—ASQ Certified Quality Auditor

CQA—contract quality assurance

CQA—corporate quality assurance

CQE—ASQ Certified Quality Engineer

CQIA—ASQ Certified Quality Improvement Associate

CQM—Center for Quality of Management

CQMP—clinical quality management program

CQP—corporate quality policies

CQPA—ASQ Certified Quality Process Analyst

CQR—contract quality requirement

CQT—ASQ Certified Quality Technician

CR—conditionally required

Cr—ratio of process variation

CR/CR—concern report/change request

CRA—chemical risk assessment

CRE—ASQ Certified Reliability Engineer

CRM—certified reference material

CRM—corporate records management

CRM—customer relationship management

CS—customer satisfaction

CSA—compliance safety accountability

CSF—critical success factors

CSI—critical safety items

CSM—customer–supplier model

CSP—Certified Safety Professional

CSP—continuous sampling plan

CSQE—ASQ Certified Software Quality Engineer

CSSBB—ASQ Certified Six Sigma Black Belt

CSSGB—ASQ Certified Six Sigma Green Belt

CSSMBB—ASQ Certified Six Sigma Master Black Belt

CSSYB—ASQ Certified Six Sigma Yellow Belt

CT—controlled tables

CTC—critical to customer

CTQ—critical to quality

CTS—critical to satisfaction

CUSUM—cumulative sum control chart

CVEP—continuous value enhancement process

CWA—Clean Water Act

CWAP—clean water action plan

CWQC—company-wide quality control

D—detection

DAX—desire, attitude, execution

DBR—discounted cash flow

DCCDI—define–customer–concept–design–implement

DCF—discounted cash flow

DCMA—Defense Contract Management Agreement

DCOV—define–characterize–optimize–verify

DCP—dynamic control plan

DDW—drill deep and wide

DE—directed evolution

DER—designated engineering representative

df—degrees of freedom

DFA—design for assembly

DFD—design for disassembly

DFE—design for ergonomics

DFM—design for manufacturing

DFMA—design for manufacturing and assembly

DFMEA—design failure mode and effects analysis

DFSS—design for Six Sigma

DFX—design for X

DMADOV—define–measure–analyze–design–optimize–verify

DMADV—define–measure–analyze–design–verify

DMAIC—define, measure, analyze, improve, and control

DMEDI—define–measure–explore–develop–implement

DMR—discharge monitoring reports

DOE—design of experiment(s)

DOT—United States Department of Transportation

DPM—deficiencies (defects) per million units

DPM—downtime performance measurement

DPO—deficiencies (defects) per opportunity

DPU—deficiencies (defects) per unit

DQC—data quality control

DRBFM—design review based on failure mode (Toyota version of FMEA)

DRII—Disaster Recovery Institute International

DSL—digital subscriber line

DSU—digital service unit

DTD—dock to delivery

DV&PR—design verification and product reliability

DVP—design verification plan

DVP&PV—design verification, production and process validation

DVR—design verification report

DVT—design verification test

EARA—Environmental Auditors Registration Association

EC—European Community

ECC—estimated cost to complete

ECD—estimated completion date

ECDF—empirical cumulative distribution function

ECHO—enforcement and compliance history online

ECN—engineering change notice

ECO—engineer change order

ECR—engineering change request

EDA—exploratory data analysis

EDI—electronic data interchange

EI—employee involvement

EIO—engineering or installation caused outage

ELT—extract load transfer

EMI—electromagnetic interference

EMS—environmental management system

EOQ—economic order quantity

EP313—Emergency Planning and Community Right to Know Act, Section 313 (i.e., the Toxics Release Inventory (TRI) program)

EPSS—electronic performance support system

ER—engineering requirements

ERI—early return indicator

ERM—enterprise risk management

ERP—enterprise resource planning

ES—engineering specification

ESC—extreme service conditions

ESER—engineering sample evaluation report

ET—educational technology

ETA—event tree analysis

ETQ—excellence to quality

EU—European Union

EV—equipment variation

EVOP—evolutionary operation

EWMA—exponentially weighted moving average

FAHQMT—fully automatic high-quality machine translation

FAI—first article inspection

FAIR—first article inspection report

FAR—Federal Acquisition Regulation

FARA—field action risk assessment

FAST—function analysis system technique

FCE—frequently committed errors

FEA—finite element analysis

FEA—front-end analysis

FEFO—first expired, first out

FIFO—first in, first out

FIFRA—Federal Insecticide, Fungicide, and Rodenticide Act

FISH—first in still here

FMA—failure mode analysis

FMEA—failure mode and effects analysis

FMECA—failure mode effects and criticality analysis

FMEDA—failure modes, effects, and diagnostic analysis

FMEM—failure mode effects management

FPA—first party audit

FPS—Ford Production System

FQ&P—flight, quality, and performance

FQI—Federal Quality Institute (*see* OPM)

FR—field replaceable unit returns

FRT—fix response time

FSI—fatal and serious injury

FSL—flow synchronization leveling

FSP—function restoration plan

FSS—full service supplier

FST—food safety team

FTA—fault tree analysis

FTPM—Ford Total Productive Maintenance

FTQ—first time quality

FTT—first time through

G8D—global eight disciplines

GB—Green Belt

GD&T—geometric dimensioning and tolerancing

GE—General Electric Corporation

GHS—globally harmonized system

GLM—general linear model

GLP—good laboratory practice

GM—General Motors Corporation

GMP—good manufacturing practice

GPC—gage performance curve

GR&R—gage repeatability and reproducibility

GROW—goal, reality, options, way forward

GRPI—goals, roles, processes, interpersonal

GRR—gage repeatability and reproducibility

GQA—government quality assurance

GQAR—government quality assurance representative

GQTS—global quality tracking system

GSQA—government source quality assurance

GUM—*Guide to the Expression of Uncertainty of Measurement*

Ha—alternative hypothesis

HA—hazard analysis

HACCP—hazard analysis and critical control points

HALT—highly accelerated life test

HARM—high-availability, reliability, and maintainability

HASA—highly accelerated stress audits

HASS—highly accelerated stress screening
HAZOP—hazard and operability study
HCS—hazardous communication standard
HOQ—house of quality
HPT—human performance technology
HQS—high-quality screening
HR—human resources
HRM—human resources management
HSEQ—health safety environmental quality
HSPD—handling, storage, packaging, and delivery
HSSE—health safety security environment
HSSEQ—health safety security environment quality
IABLS—Institute of Advanced Business Learning Systems
IAQG—International Aerospace Quality Group
IATF—International Automotive Task Force
ICC—incident command centre
ICOFR—internal controls over financial reporting
ICOV—identify–characterize–optimize–validate
ICT—information communication technology
ID—interrelationship digraph
IDDOV—identify–define–develop–optimize–verify (and validate)
IDEA—identify–design–evaluate–affirm
IDOV—identify–design–optimize–verify (and validate)
IEC—International Electrotechnical Commission
IEEE—Institute of Electrical and Electronics Engineers
IID—independent identically distributed
IIE—Institute of Industrial Engineers
ILT—instructor lead training
IMDS—International Material Data System
IMP—incident management plan
IMR—individuals and moving range
IMS—incident management structure

INPO—Institute of Nuclear Power Operators

INT—interaction

IOBA—International Automotive Oversight Bureau

IOP—IOP The Packaging Society - Institute of Materials, Minerals, and Mining

IPIP—improving performance in practice

IPO—input–process–output

IPS—innovative problem solving

IQA—Institute for Quality Assurance

IQCS—in-service quality control system

IQF—International Quality Federation

IQR—interquartile range

IQUE—in-plant quality evaluation

IRC—issue review committee

IRCA—International Register of Certified Auditors

IRR—internal rate of return

IS—information security

ISD—instructional system design

ISIR—initial sample inspection report

ISO—International Organization for Standardization

ISPI—International Society for Performance Improvement

ISSSP—International Society of Six Sigma Practitioners

IT—industrial technology

IT—information technology (computers)

IT—instructional technology (education)

ITDR—information technology disaster recovery

ITP—inspection and test plan

ITU—International Telecommunication Union

JCAHO—Joint Commission on Accreditation of Healthcare Organizations

JDP—J. D. Power and Associates

JES—job element sheet (another name for work instructions)

JIS—Japan Industrial Standard

JIS—job instruction sheet (another name for work instructions)

JIT—just in time

JUSE—Union of Japanese Scientists and Engineers

KBC—knowledge based community

KBF—key business factors

KBI—key business issue

KBR—key business requirement

KC—key characteristic

KCC—key control characteristic

KISS—keep it simple and specific *or* keep it simple statistician

KLT—key life test

KPC—key product characteristic

KPI—key performance indicator

KPI—key process indicator

KPIV—key process input variable

KPOV—key process output variable

KSN—knowledge sharing network

LACL—lower acceptance control limit

LBC—level of business continuity

LCI—learner controlled instruction

LCL—lower control limit

LCR—linear responsibility chart (another name for RACI)

LEO—listen (observe and understand), enrich (explore and discover), and optimize (improve and perfect)

LIFO—last in, first out

LLL—lower lot limit

LMS—learning management system

LOB—line of business

LOTO—lock out tag out

LQ—limiting quality

LQIP—laboratory quality improvement program

LQL—limiting quality level

LRU—line replaceable unit

LSA—logistic support analysis

LSD—least significant difference

LSL—lower specification limit

LSS—Lean Six Sigma

LTI—lost time injury

LTPD—lot tolerance percentage defective

LTR—long-term return rate

LTS—long-term stability

m—mean

M&A—manufacturing and assembly

M&TE—measurement and test equipment

MAIC—measure, analyze, improve, and control

MAR—maximum allowable range

MBB—Master Black Belt

MBC—management of business continuity

MBO—management by objectives

MBNQA—Malcolm Baldrige National Quality Award

MBTI—Myers-Briggs Type Indicator

MBWA—management by walking around

MCF—mean cumulative function

MDR—medical device report

MEDIC—map + measure, explore + evaluate, define + describe, implement + improve, control + conform

MFMEA—machinery failure mode and effects analysis

MIL-STD—United States military standard

MIS—management information systems

MIS—months in service

MMBF—mean miles between failures

MODAPTS—modular arrangement of predetermined time standards

MOS—management operating system

MOT—moment of truth

MPRSA—Marine Protection, Research, and Sanctuaries Act

MPS—master production schedule

MQT—maintainability qualification test

MRA—mutual recognition arrangements

MRB—management review board

MRP—material requirements planning

MRSL—market required service level

MS—mean squares

MS (RES)—residual mean square

MS&R—mission solutions and readiness

MSA—measurement systems analysis

MSB—mean square between treatments

MSD—maximum standard deviation

MSDS—material data safety sheet (old phrase that should not be used any longer)

MSE—mean squared error

MSI—mean square for interaction

MSW—mean square within treatments

MT&E—measuring tools and equipment

MTBF—mean time between failures

MTC—manage the change

MTD—month to date

MTPD—maximum tolerable period of disruption

MTTF—mean time to failure

MTTN—mean time to notification

MTTR—mean time to recover

MTTR—mean time to repair

MWO—maintenance work order

NA—needs assessment

NA *or* **N/A**—not applicable

NACCB—National Accreditation Council for Certification Bodies

NADCAP—National Aerospace and Defense Contractors Accreditation Program

NATO—North Atlantic Treaty Organization

NCT—nonconformance ticket

ndc—number of distinct categories

NDE—nondestructive evaluation

NDT—nondestructive testing

NE *or* **N/E**—not evaluated

NGT—nominal group technique

NIH—not invented here

NIST—United States National Institute of Standards and Technology

NMI—near miss incident

NMQAO—Naval Material Quality Assessment Office

NPI—new product introduction

NPR—number of problem reports

NPV—net present value

NQCC—network quality control center

NTF—no trouble found

NTRM—NIST Traceable Reference Material

NVA—non-value-added

NVA-U—non-value-added, but unavoidable

NVH—noise, vibration, and harshness

O—occurrence

OASIS—Online Aerospace Supplier Information System

OBC—operator base care

OBS—observation

OC—operating characteristic

OCAP—out-of-control action plan

OCC—operating characteristic curve

OCM—operating committee meeting

OCM—organizational change management

OCS—operational control sheet (another name for control sheet)

OCT—operations cost target

OD—organization development

OE—organizational excellence

OEE—overall equipment effectiveness

OEM—original equipment manufacturer

OFI—opportunity for improvement

OFM—outage frequency measurement

OFR—overdue fix responsiveness

OHS—occupational health and safety

OI—operating instructions

OJT—on-the-job training

OLE—overall labor effectiveness

OOC—out of stock

ORT—ongoing reliability test

OSHA—United States Occupational Safety and Health Administration

OSS—operational support system

OTD—on-time delivery

OTED—one touch exchange of dies

OTI—on-time item delivery

OTIS—on-time installed system delivery

OTS—on-time service delivery

P&L—profit and loss

P&S—products and services

P/T—precision/tolerance

PaR—patients at risk

PAR—preventive action report

PART—program assessment rating tool

PAT—part average testing

PBC—process behavior charts

PBIB—partially balanced incomplete block design

PC—physical contradiction

PC—product complaint

PCD—process control document

PCR—product change request

PCS—production control system

PDA—personal data assistant

PDC—product development cycle

PDE—Proposal Development Engineer

PDCA—plan–do–check–act

PDM—precedence diagram method

PDPC—process decision program chart

PDQR—product quality deficiency reports

PDSA—plan–do–study–act

PE—professional engineer

PEL—permissable exposure limits

PERT—program evaluation review technique

PEST—political, economic, social and technological

PESTLE—political, economic, social, technology, legal, environmental

PFMEA—potential failure mode and effects analysis

PFQ—planning for quality

PI—principal inspector

PIPC—percent indices which are process capable

PISMOEA—part, instrument, standard, method, operator, environment, assumptions

PIST—percentage of inspection points satisfying tolerance

PIT—process improvement team

PM—preventive maintenance

PM—program management

PMA—premarket approval

PMA—president's management agenda

PMO—deficiencies (defects) per million opportunities

PMP—project management professional

PMS—planned maintenance system

PMTS—predetermined motion time system

PO—purchase order

POI—program of instruction

PONC—price of nonconformance

Pp—long-term process capability measurement

PP&B—prototype planning and build

PP&DC—product planning and design committee

PP&TC—product planning and technology committee

PPAP—production part approval process

PPCC—normal probability plot correlation coefficient

PPF—production process and product approval

Ppk—long-term process capability measurement

ppm—parts per million

PPPPP—prior planning prevents piss-poor performance

PPPPPP—proper planning prevents particularly poor performance

PPR—patients per run

PPS—production preparation schedule

PQ—process qualification

PQA—President's Quality Award

Pr—capability performance ration

PR—production release

PRAT—production reliability acceptance test

PRP—process recovery plan

PRR—problem reporting and resolution *or* product problem reporting

PSM—process safety management

PSO—process sign-off

PSP—problem-solving process

PSP—product support plan

PSW—part submission warrant

PTC—pass through characteristics

PTN—plant test number

PUMA—product usage measurements and applications

PV—part variation

PVP&R—production validation plan and report

PYR—pass yield rate

Q&R—quality and reliability

QA—quality assurance

QA—quick action

QAA—quality assurance analyst

QAA—quality assurance and assistance

QAA—quality assurance assessment

QAA—quality assurance audit

QAC—quality assurance checklist

QAC—quality assurance committee

QAD—quality assurance directorate

QAD—quality audit division

QADR—quality assurance discrepancy report

QAE—quality assurance engineer

QAE—quality assurance evaluation

QAE—quality assurance executive

QAER—quality acceptance equipment release

QAF—quality achievement factor

QAF—quality assurance fixture

QAF—quality assurance form

QAHB—Quality Assurance Program Handbook

QAI—quality assessment index

QAI—Quality Assurance Institute

QAI—quality assurance instruction

QALI—quality assurance letter of instruction

QAM—quality assurance manager

QAM—quality assurance monitoring

QAN—quality action notice

QAPI—quality assurance program index

QAPR—Quality Army Performance Review

QAR—quality acceptance report

QAR—quality assurance and reliability

QAR—quality assurance evaluator

QAR—quality assurance requirements

QAR—quality assurance review

QAR—quantitative analysis report

QAR—quarterly acceptance review

QARC—Quality Assurance Review Center

QAS—quality assurance, auditing, and security

QAS—quality assurance schedule

QAS—quality assurance screening program

QAS—quality assurance standard(s)

QAS—quality assurance study

QAS—quality assurance surveillance

QAS—quality assurance test system

QASP—quality assurance support plan

QATAP—quality assurance through attributes program

QATDP—quality assurance technical development program

QBP—quality and business planning

QC—quality center

QC—quality control

QCAI—quality control/assurance and inspection

QCCMM—quality control certified master model

QCE—quality control engineering

QCEM—quality control enforcement mechanism

QCI—Quality Circle Institute

QCI—quality control information

QCI—quality cost improve(ment)

QCI—Quality Council of India

QCI—Quality Council of Indiana

QCM—quality call monitoring

QCM—quality care monitoring

QCM—quality control manual

QCM—quality control master

QCP—quality commitment performance

QCP—quality control program

QCR—quality control reliability

QCR—quality control report

QCR—quality control representative

QCS—quality and customer satisfaction

QCS—quality customer service

QCT—quality, cost, timing

QCWF—quality, cost, weight, and function

QCWFT—quality, cost, weight, function, and timing attributes

QDR—quality, durability, reliability

QDR—quality deficiency report(s)

QEMS—quality and environmental management system

QEP—quality enhancement program

QEP—quality evaluation program

QF—quality form

QFD—quality function deployment

QFTF—quality function test fleet

QHC—quality in health care

QHNZ—Quality Health New Zealand

QHR—quality history records

QI—quality improvement

QI—quality increase

QIC—quality information using cycle time

QIES—quality improvement evaluation system

QIM—quality improvement meeting

QIP—quality improvement process

QIP—quality intervention plan

QIS—quality information system

QIT—quality in training

QIT—quality information and test

QITQM—*Quality Improvement Total Quality Management* (magazine)

QLA—quality level agreement

QLF—quality loss function

QLS—quality leadership system

QMAS—Quality Measurement Advisory Service

QMIS—quality management information system

QMMP—Quality Measurement and Management Project

QMP—quality, manufacturing, and purchasing

QMRP—Qantel manufacturing resource planning (MRP II) system

QMS—quality management system

QOS—quality of service

QOS—quality operating system

QP—quality plan

QP—quality procedure

QPC—quality and process control

QPC—quality performance consultant

QPI—quality performance indicator

QPIP—quality and productivity improvement program

QPM—quality and performance management

QPM—quality performance matrix

QPM—quality program manager

QPR—quality problem report

QPS—quality planning sheets

QPS—quality process sheets

QPS—quality process system

QPSS—quality process system sheets

QR—quality and reliability

QR—quality reject(s)

QR—quality report

QR—quantitative requirement

QR—quick response

QRA—quality and reliability assurance

QRA—quality reliability assurance

QRA—quick reaction assessment

QRA—quick readiness assessment

QRA—quick response audit

QRB—quality review board

QRC—quality record coordinator

QRC—quality risk and cost

QRD—quantitative risk management

QRM—quality risk management

QRO—quality review organization

QRS—quality review studies

QRT—quality responsible team

QS—quality systems

QS-9000—Quality System Requirements 9000

QSA—quality system analyst

QSC—quality strategy committee

QSDC—quality system document coordinator

QSF—quick service fix

QSHC—*Quality and Safety in Health Care* (magazine)

QSP—quality strategy and planning

QSR—quality system requirement(s)

QSRC—quality system record coordinator

QSS—quality support team

QSU—quality system update

QTS—quality tracking study

QUADS—quality document system

QUASAR—Quality and Safety Achievement Recognition

QUASAR—Quality Driven Software Architecture

QUEST—quality electrical systems test

QUEST—quality evaluation of settlement

QuEST—Quality Excellence for Suppliers of Telecommunications

QUGS—quality utilization generic screens

QUIP—quality assessment and improvement program

QUIP—quality assurance inspection procedure

QUIT—Quality in Training

QVI—quality verification inspection

QVP—quality vendor program

R—required

R^2—coefficient of determination

R2R—runs to reject

R&A—reliability and availability

R&D—research and development

R&M—reliability and maintainability

R&M—reliability and maintenance

R&MWG—reliability and maintainability working group

R&R—repeatability and reproducibility (*see also* GR&R)

RA—risk analysis

RA—risk assessment

RAB—registrar accreditation board

RABQSA—RABQSA International (formerly the Registrar Accreditation Board and the Quality Society of Australasia)

RACI—responsible, accountable, consulted, and informed

RADHAZ—radio and radar radiation hazards

RAM—reliability, availability, and maintainability

RAM—responsibility assignment matrix

RAMAS—reliability, availability, maintainability analysis system

RAMCAD—reliability and maintainability in computer-aided design

RAM-D—reliability, availability, maintainability, and durability

RAMDAS—reliability and maintainability data access system

RAMES—reliability, availability, maintainability, engineering system

RAMIS—reliability and maintainability information system

RAMS—range measurement system

RAMSH—reliability, availability, maintainability, safety, (and) human-factors (engineering)

RAMTIP—Reliability and Maintainability Technology Insertion Program

RAPID—rapid actions for process improvement deployment

RAS—reliability, availability, and serviceability

RBD—reliability block diagram

RBI—risk based inspection

RBM—risk based maintenance

RC—responsible care

RCA—root cause analysis

RCL—robustness checklist

RCM—reliability centered maintenance

RCPS—root cause problem solving

RCRA—Resource Conservation and Recovery Act

RD/GT—reliability development/growth test

RDCOV—recognize–define–characterize–optimize–verify

REG—regression

REM—reliability engineering model

RES—residual

RF—radio frequency

RF—remaining float

RFI—radio frequency interference

RFP—request for proposal

RFQ—request for quote

RFTA—reverse fault tree analysis

RII—required inspection item

RIW—reliability improvement warranty

RM—reference material

RM&A—reliability, maintainability, and availability

RM&S—reliability, maintainability, and supportability

RMA—reliability, maintainability, and availability

RMMP—reliability and maintainability management plan

RMS—root mean square

ROA—report of analysis

ROA—return on assets

ROE—return on equity

ROI—return on investment

RONA—return on net assets

RPL—rejectable process level

RPM—revolutions per minute

RPN—risk priority number

RPO—recovery point objective

RQL—rejectable quality level

RQMS—*Reliability and Quality Measurements for Telecommunications Systems*

RQL—rejectable quality level

RQT—reliability qualification test(ing)

RRA—residual risk assessment

RRM—risk review meeting

RSM—repair station manual

RSM—response surface methodology

RTO—recovery time objective

RtO—return to operation

RTOK—retest OK

RTY—rolled throughput yield

S—satisfactory

S—severity

S3—safety and suitability for service

SAE—Society of Automotive Engineers *or* SAE International

SAES—supplier audit evaluation summary

SB—service bulletin

SBP—strategic business plan

SC—significant characteristic

SCM—supply chain management

SCOT—strengths, challenge, opportunities, threats

SCP—service control point

SDCA—standardize–do–check–act

SDE—supplier development engineer

SDS—safety data sheet

SDWA—Safe Drinking Water Act

SDWT—self-directed work team

SE—simultaneous engineering

SE—standard error

SEP—safety and environmental procedure

SET—senior executive team

SF—secondary float

SHARP—Safety and Health Achievement Recognition Program

SIF—safety integrity analysis

SIPOC—supplier, input, process, output, and customer

SIT—systematic inventive thinking

SKSP—skip-lot sampling plan

SLACK—summary, learning objectives, application, context, knowledge base

SMART—specific, meaningful, agreed to, realistic, time-based

SMARTER—specific, measurable, acceptable, realistic, time-bound, evaluated, reviewed

SME—Society of Manufacturing Engineers

SME—small and medium enterprises

SME—subject matter expert

SMED—single-minute exchange of die

SMS—safety management system

SN—signal-to-noise ratio

SO—system outage measurement

SoA—statement of applicability

SOC2 Type 2—Service Organization Control audit related to ISO 27001

SOF—safety of flight

SOP—standard operating procedure

SoPK—System of Profound Knowledge (Dr. W. Edwards Deming)

SOQ—service-oriented architecture

SOR—sign-off report

SOS—standard operating sheets (another name for work instructions)

SOW—statement of work

SOW—Scope of work

SPA—second party audit

SPC—statistical process control

SPD—statistical process display

SPEAR—suppler performance and evaluation report

SPM—statistical process management

SPOF—single point of failure

SPOT—scope, purpose, overview, tangible benefits

SQC—statistical quality control

SQDCME—safety, quality, delivery, cost, moral, environment

SQA—supplier quality agreement

SQE—software quality evaluation

SQE—supplier quality engineer

SQI—supplier quality improvement

SQP—strategic quality plan

SQR—supplier quality representative

SQRTF—Supplier Quality Requirements Task Force

SREA—supplier request for engineering approval

SRG—statistical research group

SRM—supplier relationship management

SRMR—security risk management review

SRP—strategic regulatory plan

SS—Six Sigma

SS—sum of squares

SSB—between-treatments sum of squares

SSBB—Six Sigma Black Belt

SSBoK—Six Sigma Body of Knowledge

SSC—column sum of squares

SSE—error sum of squares

SSGB—Six Sigma Green Belt

SSI—interaction sum of squares

SSMBB—Six Sigma Master Black Belt

SSOS—Six Sigma operating system

SSR—residual sum of squares

SSR—row sum of squares

SSRA—system safety risk assessment

SST—total sum of squares

SSW—within-treatments sum of squares

SSYB—Six Sigma Yellow Belt

STA—supplier technical assistance

STD—standard deviation

STEL—short-term exposure limit

STF—Slip Trip & Fall

STOP—Safety Training Observation Program

STP—signaling transfer point

STS—synchronous transport signal

SUTR—set-up time reduction

SVA—source vulnerability assessment

SWAG—statistical wild ass guess

SWIPE—standard, workpiece, instrument, person and procedure, environment

SWL—safe working load

SWOT—strengths, weaknesses, opportunities, threats

T—target

T&D—test and diagnostic

T&D—training and development

T&E—test and evaluation

T&EO—training and evaluation outline

T&M—time and materials

T&O—test and operation

TACT—total average cycle time

TAT—turnaround time

TBD—to be determined

TBE—to be established

TC—technical contradiction

TDR—technical design review(s)

TE—tooling and equipment

TF—total float

TGR—things gone right

TGW—things gone wrong

TIE—technical information engineer

TMAP—thought process map

TNA—training needs assessment

TNA—training needs analysis

TOC—theory of constraints

TOPS—total operational performance system

TOU—terms of use

TPA—third-party audit

TPI—transaction process improvement

TPM—total productive maintenance

TPS—Toyota Production System

TQ—total quality

TQC—total quality control

TQHRM—total quality human resources management

TQM—total quality management

TRACE—total risk assessing cost estimate

TRACE—total risk assessing cost estimating

TRIZ—theory of inventive problem solving

TRLT—total replenishment lead time

TS—technical specification

TSCA—Toxic Substances Control Act

TSS—total sum of squares

TTI—targets to improve

TV—total variation

TVM—total value management

TWA—time weighted average

UACL—upper acceptable control limit

UCL—upper control limit

UKAS—United Kingdom Accreditation Service

ULL—upper lot limit

UP—unit price

UPC—uniform parts code

UQL—unacceptable quality level

UPS—uninterrupted power system

USL—upper specification limit

USPAP—Uniform Standards of Professional Appraisal Practice

V&V—verification and validation

VA—value-added

VA/VE—value analysis/value engineering

VC—virtual container

VDA—Verband der Automobilindustrie (German)

VIM—*International Vocabulary of Metrology—Basic and General Concepts and Associated Terms*

VIN—vehicle identification number

VIPER—verifiable integrated processor for enhanced reliability

VOB—voice of the business

VOC—voice of the customer

VOE—verification of effectiveness

VOE—voice of the employee

VOP—voice of the process

VPC—vendor product complaint

VPP—voluntary protection program

VQD—visual quality document

VSAS—vehicle situational awareness system

WAG—wild ass guess

WBS—work breakdown structure

WCP—world class process

WGD—worldwide guidance documents

WI—work instructions

WIIFM—what's in it for me

WIP—work in process

WOW—worst of the worst

WPS—Weld Procedure Specifications

WQP—worldwide quality procedures

WQS—worldwide quality standards

WUR—water use ratio

WYSIWYG—What you see is what you get

x**—**average

X**—**cause or process variable

Y—effect or process output

YRR—one-year return rate

ZD—zero defects

Appendix N

The Quality Profession, Historically Speaking

SELECTED NOTES OF EVENTS

1750's	Industrial Revolution begins in England
1760	Lloyd's Registrar starts auditing ship yards – charged ship builders – third party registration
January 22, 1901	Sir John Wolfe-Barry (the man who designed London's Tower Bridge) instigated the Council of the Institution of Civil Engineers to form a committee to consider standardizing iron and steel sections
1911	Frederick W. Taylor publishes "The Principles of Scientific Management"
December 1, 1913	Henry Ford installs the first moving assembly line for the mass production of an entire automobile
1919	The Technical Inspection Association (TIA) forms (forerunner of CQI)
1922	The TIA becomes the Institution of Engineering Inspection (IEI)
1924	Walter A. Shewhart, a statistician at Bell Laboratories, develops the control charts, and principles of statistical process control
1925	Sir Ronald Fisher publishes the book, Statistical Methods for Research Workers, and introduced the concept of ANOVA
1927-1933	Elton Mayo at Western Electric plant in Cicero IL – Harvard Business School – Hawthorne Studies
1930s	Statistical Quality Control (SQC) – application of statistics to quality control
1931	Shewhart publishes *Economic Control of Quality of Manufactured Products*
1937	Joseph Juran introduces the Pareto principle as a means of narrowing on the vital few
1940	The acceptance sampling plan is developed by Harold F. Dodge and Harry G. Roming
1943	Kaoru Ishikawa develops the cause and effect diagram (Ishikawa or fishbone diagram)

1943	Federated Societies forms: Society of Quality Control Engineers of Buffalos (Buffalo Section 0201); Michigan Society for Quality Control (Greater Detroit Section 1000); Quality Control Engineers of Rochester (Rochester Section 0204); The Society of Quality Control Engineers of Syracuse (Syracuse Section 0206)
1944	Industrial Quality Control Vol 1 No 1 July 1944 – Society of Quality Control Engineers with cooperation of the University of Buffalo
1944	Dodge and Roming publish *Sampling Inspection Tables Single and Double Sampling*
February 16, 1946	The American Society for Quality Control (ASQC) is formed
May 1946	The Union of Japanese Scientists and Engineering (JUSE) established
February 23, 1947	The International Organization for Standardization (ISO) founded Geneva, Switzerland
1947	Dr. W. Edwards Deming is sent to Japan to help Japanese rejuvenate their industries
1948	Shewhart Medal First Awarded by ASQC
November 9, 1949	USA Military Procedure MIL-P-1629, Procedures for Performing a Failure Mode, Effects and Criticality Analysis (FMECA) forerunner to Mil-Q-1629 Procedures for Performing a FMECA (later the FMEA) – 1974, 1977, MIL-STD 1629A:1980
1950	Genrich Altshuller develops the theory of inventive problem solving (TRIZ)
1950	JUSE publishes *Elementary Principles of The Statistical Control of Quality* by Deming
1951	JUSE institutes the Deming Prize
1951	Juran publishes the first edition of *Quality Control Handbook*
1951	Feigenbaum publishes the first edition of *Total Quality Control (QC Principles, Practices & Administration*
1954	JUSE invites Juran to Japan
@ 1955	England Training Film: Right First Time *The Deming Institute own copyright
1956	Western Electric Company publishes *Statistical Quality Control Handbook*
1956	Total Quality Control (TQC) – Feigenbaum book & articles
April 9, 1959	Mil-Q-9858:1959 – Military Specification: Quality Program Requirements
1959	Edwards Medal first awarded by ASQC
1959	Donald Kirkpatrick's Learning Evaluation Model
1959	ASQC and the American Statistical Association jointly create *Technometrics*
1960s	The first "quality control circles" are formed in Japan and simple statistical methods were used for quality improvement

1960s	Statistical Process Control (SPC) – use of control charts to monitor processes
1960s	The concept of Kaizen is developed
1960	ASQC Education and Training Institute Board is formed
1962	Japan Productivity Center opens in USA (founded 1955)
1961-1964	The concept of Poka Yoke is developed by Shigeo Shingo
1963	Mil-Q-9858A:1963 – Military Specification: Quality Program Requirements
1964	Ford Motor Company issues the first Q-101 for suppliers – Canada version 1965
1966	Dr. Yoji Akao introduces Quality Function Deployment (QFD) Methodology
1967	Grant Medal first awarded by ASQC
1968	ASQC Certified Quality Engineer develop – 1st professional certification in quality
1968	Company-Wide Quality Control (CWQC) – Japanese style total quality
1968	Kaoru Ishikawa publishes the Guide to Quality Control
1968	ASQC *Industrial Quality Control* is replaced by two new publications, *Quality Progress* magazine and *The Journal of Quality Technology*
1969	Dr. Shingo Shigeo, as part of JIT, pioneers the concept of Single Minute Exchange of Dies (SMED)
1969	Ishikawa emphasizes the use of Seven Quality Tools
1969	ASQC co-sponsors the first International Congress in Quality Control, hosted by the Union of Japanese Scientists and Engineers in Tokyo
1970s	Dr. Taguchi promotes the concept of Quality Loss Function
1973	ASQC publishes *Glossary & Tables for Statistical Quality Control*
1977	International Association for Quality Circles founded
1979	BS 5750 is issued. This was later replaced with ISO 9001:1987
1979	Philip Crosby publishes his book "Quality is Free."
1979	Deming Medal First Awarded by the ASQC Metropolitan Section and ASQC 1996
June 24, 1980	NBC airs the television documentary "If Japan Can, Why Can't We?" narrated by Lloyd Dobyns
1980s	Professor Noriaki Kano develops the Kano model which classifies customer preferences into five categories: Attractive, One-Dimensional, Must-Be, Indifferent, Reverse
1980	QCI International is founded by Donald Dewar
1981	Lancaster Medal first awarded by ASQC
1981	*Quality Digest* – first issue published under the title *Quality Circle Digest*

@ 1981	Eastern Michigan University begins developing first Master in Quality with Ford Motor Co & W. Edwards Deming
1982	*Out of the Crisis*, published in 1982, Deming offers a theory of management based on his famous 14 Points for Management
@ 1982	Transformation of American Industry – jointly developed by Ford Motor, Jackson Community College & W. Edwards Deming
1984	The Register of Lead Assessors is created and evolves to the International Register of Certificated Auditors (IRCA)
1984	October is designated National Quality Month by USA Congress
1985	NASA Excellence Award is established
1985	Total Quality Management – USA Department of Defense drive for organizational improvements
1986-1988	Six Sigma formulated by Bill Smith in Motorola
1986	Masaaki Imai establishes the Kaizen Institute to help Western companies introduce Kaizen concepts, systems, and tools
March 15, 1987	ISO issues the first version of the ISO 9000 series. (ISO 9001:1987)
1987	Malcolm Baldrige National Quality Award is established.
1987	*Quality Circle Digest* drops "Circle" from its name to become *Quality Digest*
1988	ASQ Certified Quality Auditor established
1988	ISO 9001:1988 Quality management systems – Requirements – 2nd 1994, 3rd 2000, 4th 2008, 5th 2015, 6th TBD
1988	Motorola becomes the first company to win Malcolm Baldrige National Quality Award
1988	Ford Motor Company creates Supplier Quality Improvement (SQI) – first pre-launch supplier program in the USA (tied to APQP) – merged with SQA in 1993
September 15, 1988	Presidents of 14 European companies come together to create the European Foundation for Quality Management
1989	IQA celebrates the first World Quality Day on 9 November 1989
1990	Registrar Accreditation Board (RAB) is founded to support ISO 9001
1990	AIAG Measurement System Analysis (MSA) – 2nd 1995, 3rd 2002, 4th 2010
1991	ASQC exceeds 100,000 members
@ 1992	General Electric officially adopts Six Sigma
1992	AIAG Statistical Quality Control (SPC) – 2nd 2005
1992	ISO 19011:1992 Guidelines for auditing management systems – 2nd 2010, 3rd 2018
1993	Ishikawa Medal first awarded by ASQC
1993	AIAG Production Part Approval Process – 2nd 1995, 3rd 1999, 4th 2006

1993	AIAG Failure Modes & Effects Analysis (FMEA) – 2nd 1995, 3rd 2001, 4th 2008
1993	*Quality Management Journal* debuts
1994	The First American Customer Satisfaction Index is released
1994	Eleven elementary schools participate in the Koalaty Kid training initiative
1994	AIAG USA Automotive Industry releases Advance Product Quality Planning & Control Plan (APQP) – 2nd Ed 2008
1994	Quality Systems Requirements 9000 (QS-9000) quality standard developed by a joint effort of the 'Big Three' automakers, GM, Chrysler, and Ford – 2nd 1996, 3rd 1998
1994	ISO issues the second version of the ISO 9000 series. (ISO 9001:1994)
1994	ISO 9001:1994 Quality management systems – Requirements
1994	SAE International releases J1739:1994 Surface Vehicle Recommended Practice FMEA – 2000, 2002, 2009, 2021
1995	ASQ Certified Quality Manager program is developed
1995	General Electric (GE) launches the Six Sigma initiative
1996	ASQ announces the Pioneers In Quality
1996	ISO 14001:1996 Environmental management systems – Requirements – 2004, 2015
1996	ISO 13485:1996 Medical devices – Quality management systems – Requirements for regulatory purposes released (1996, 2003, 2016)
1997	ASQC drops 'Control' from its name, becomes ASQ
1998	Ford Motor Company launches Six Sigma Black Belt training for 3,000 personnel
1998	ASQ is named administrator of the QuEST Forum, which develops the TL 9000 telecommunications standards
1998	The journal *Software Quality Professional* debuts
1998	ASQ rolls out Six Sigma black belt training for individuals and organizations
1999	ISO/TS 16949:1999 – 1st Edition is released with updates 2002, 2009
1999	British Standards (BS) OHSAS 18001:1999 – Occupational Health and Safety Assessment – updated 2007 – migrates to ISO 45001:2018
2000	ISO issues the third version of the ISO 9000 series. (ISO 9001:2000)
2000	Juran Medal first awarded by ASQ
2000	Feigenbaum Medal first awarded by ASQ
2000	ISO 9001:2000 Quality management systems – Requirements
2000	A "Hazard Analysis and Critical Control Point" (HACCP) add-on is developed for the ASQ Certified Quality Auditor program

2000	ASQ's WorldPartner Program is founded
2001	ASQ Certified Quality Improvement Associate (CQIA) program is introduced
2001	ASQ relocates to the ASQ Center, its current world headquarters, in the landmark Gimbel's building in downtown Milwaukee
2001	ASQ's Six Sigma Forum is launched
2001	*Six Sigma Forum Magazine* debuts
2001	*Gazeta Global*, an international newsletter, is founded
2001	Freund-Marquardt Medal First Awarded by ASQ
2001	Lean Six Sigma – blending of Lean & Six Sigma
2002	Distinguished Service Medal First Awarded by ASQ
2002	Crosby Medal First Awarded by ASQ
2002	Calibration Technician Certification is introduced
2003	The Association for Quality and Participation (AQP) merges with ASQ
2004	ASQ Costa Rica becomes the first International Member Unit (equivalent to a Section) outside of North America
2004	Shainin Medal first awarded by ASQ
2004	ISO 14001:2004 Environmental management systems – Requirements – 2nd 2015
2005	ASQ China subsidiary is established
2005	Annual Quality Congress (AQC) changes name to World Conference on Quality and Improvement (WCQI)
2005	First certification for Quality Process Analysts is offered
2006	ASQ launches initiative to promote the Economic Case for Quality
2006	ASQ is named secretariat for the US TAG to the ISO Committee on Social Responsibility
2006	The IQA is awarded Royal Charter status
2006	Quality Magazine launched *Quality Plant of the Year* & *Quality Professional of the Year* – Roderick Munro named first recipient of Professional
2007	The IQA reforms as the Chartered Quality Institute
2007	Ron Atkinson is the first Canadian to serve as ASQ president
2007	British Standard releases BSI 18001:2007 Occupational health and safety management systems – Requirements released
2007-2009	Robert Woods Johnson Foundation sponsors Improving Performance In Practice (IPIP) for the Medical Industry
2008	ISO issues the fourth version of the ISO 9000 series. (ISO 9001:2008)
2008	ISO 9001:2008 Quality management systems – Requirements
2009	Hutchens Medal first awarded by ASQ

2011	ISO 50001:2011 Energy management systems – Requirements – 2nd 2018
2015	ISO issued the ISO 9001:2015 & ISO 14001:2015 under Annex SL
2015	ISO 9001:2015 Quality management systems – Requirements
2016	International Automotive Task Force (IATF) – IATF 16949:2016
2015	ISO 14001:2015 Environmental management systems – Requirements
2017	The CQI launches the inaugural International Quality Awards
2017	Hromi Medal first awarded by ASQ
2018	ISO 45001:2018 Occupational Health and Safety management systems – Requirements – replaces OHSAS 18001
2019	ISO 22301:2019 Security and resilience – Business continuity management systems – Requirements released
2020	COVID-19 world wide pandemic – things become more virtual
2021	Subir Chowdhury named to ASQ Distinguished Service Award

Appendix O

Rice & Munro Training Evaluation Model

The Rice & Munro Training Evaluation Model was derived from and expanded upon the *Kirkpatrick Model of Training Evaluation*. In the Kirkpatrick Model, there are typically four levels of evaluation:

> **Level 1:** Reaction to the learning event (sometime called the "Smiley Sheet") – conducted immediately on completion of the training event.
>
> **Leve 2:** Learning Gain—how much new learning occurred during the event (typically evaluation with a pre/post test or just a skills test). This is conducted immediately upon completion of the training/learning event. Example: the driving test a new forklift driver has to show that they understand the machine.
>
> **Level 3:** Learner usage over time and level of useful information to their respective jobs. Usually conducted about six months to one year after the learning event.
>
> **Level 4:** Manager (supervisor) observations of applied skills. Usually conducted about one year to a year and a half after the learning event.
>
> **Optional** – Level: Return on Investment (ROI) for sending personnel through the training with improved productivity back on the job (sometimes included in Level 4).

The practical application of the Kirkpatrick model noted that most of the time, the physical analysis of both the Level Three and Level Four was not completed as time was not available to conduct the analysis. This left many learning interventions in limbo as training had to rely on experience versus data in ways to improve the learning interventions being created by many organizations. The other challenge was that if the training was delivered by consultants or professional training organizations, they might not have access to the attendee or attendee managers in the timing needed to conduct the analysis.

The Rice & Munro Training Evaluation Model was designed to address the issues with lack of data for the Level Three and Level Four analysis. In what should be all cases, any training/learning intervention should have a stated list of learning objectives for that effort to help new learners. Given that the Human Resource (HR) function of any organization should have who took which courses (or at least the attendee's supervisor), then there should be some record of what was supposed to have been learned by the employee who took the training. The HR or Training

Coordinator can then review when employees took what training programs and determine when the Level 3 and Level 4 need to be conducted. From the learning goals, questions can then be developed on what information would be useful to understand if the training was useful to the employee, was there value in the learning at the time of delivery, what needs to be changed for practical application back on the job, what the supervisor sees as value to their personnel attending the learning, etc.

Armed with this information, but lacking the time to physically go out and track down the personnel who need to be questioned, the Training Coordinator should provide both the questions and who needs to be asked what questions, to the ISO Internal Audit Coordinator for inclusion by the internal auditors when they are auditing the departments with the targeted employees.

Given that all ISO Management System registrations (examples: ISO 9001, ISO 14001, ISO 45001, ISO 50001, ISO 22301, etc.) require ongoing internal audits to be conducted, this becomes a practical method for the Training Coordinators to have access to course attendees without having to go out and physically conduct the interviews themselves. The full course data may take a little longer to collect; however, functionally, courses will have the full data needed to make meaningful program adjustments as needed.

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Glossary

A

acceptance number—The maximum number of defects or defectives allowable in a sampling lot for the lot to be acceptable.

acceptance quality limit (AQL)—In a continuing series of lots, a quality level that, for the purpose of sampling inspection, is the limit of a satisfactory process average.

acceptance sampling—Inspection of a sample from a lot to decide whether to accept that lot. There are two types: attributes sampling and variables sampling. In *attributes sampling*, the presence or absence of a characteristic is noted in each of the units inspected. In *variables sampling*, the numerical magnitude of a characteristic is measured and recorded for each inspected unit; this involves reference to a continuous scale of some kind.

acceptance sampling plan—A specific plan that indicates the sampling sizes and associated acceptance or nonacceptance criteria to be used. In attributes sampling, for example, there are single, double, multiple, sequential, chain, and skip-lot sampling plans. In variables sampling, there are single, double, and sequential sampling plans. For detailed descriptions of these plans, see the standard ANSI/ISO/ASQ A3534-2-1993: *Statistics—Vocabulary and symbols—Statistical quality control.*

accuracy—The closeness of agreement between a test result or measurement result and the accepted/true value.[2]

activity based costing—An accounting system that assigns costs to a product based on the amount of resources used to design, order, or make it.

activity network diagram—A diagram that links tasks with direct arrows showing the path through the task list. Tasks are linked when a task is dependent on a preceding task.[3] (AKA *arrow diagram.*)

Advanced Product Quality Planning (APQP)—High-level automotive process for product realization, from design through production part approval.

affinity diagram—A management tool for organizing information (usually gathered during a brainstorming activity).

American National Standards Institute (ANSI)—A private, nonprofit organization that administers and coordinates the U.S. voluntary standardization and conformity assessment system. It is the U.S. member body in the International Organization for Standardization, known as ISO.

American Society for Quality (ASQ)—A global community of people dedicated to quality who share the ideas and tools that make our world work better. With individual and organizational members around the world, ASQ has the reputation and reach to bring together the diverse quality champions who are transforming the world's corporations, organizations, and communities to meet tomorrow's critical challenges.

analysis of means (ANOM)—A statistical procedure for troubleshooting industrial processes and analyzing the results of experimental designs with factors at fixed levels. It provides a graphical display of data. Ellis R. Ott developed the procedure in 1967 because he observed that nonstatisticians had difficulty understanding analysis of variance. Analysis of means is easier for quality practitioners to use because it is an extension of the control chart. In 1973, Edward G. Schilling further extended the concept, enabling analysis of means to be used with nonnormal distributions and attributes data in which the normal approximation to the binomial distribution does not apply. This is referred to as *analysis of means for treatment effects*.

analysis of variance (ANOVA)—A basic statistical technique for determining the proportion of influence a factor or set of factors has on total variation. It subdivides the total variation of a data set into meaningful component parts associated with specific sources of variation to test a hypothesis on the parameters of the model or to estimate variance components. There are three models: fixed, random, and mixed.

analytical (inferential) studies—A set of techniques used to arrive at a conclusion about a population based upon the information contained in a sample taken from that population.[1]

arrow diagram—A planning tool used to diagram a sequence of events or activities (nodes) and their interconnectivity. It is used for scheduling and especially for determining the critical path through nodes. (AKA *activity network diagram*.)

assignable cause—A name for the source of variation in a process that is not due to chance and therefore can be identified and eliminated. Also called "special cause."

attributes (discrete) data—Go/no-go information. The control charts based on attributes data include percent chart, number of affected units chart, count chart, count per unit chart, quality score chart, and demerit chart.

attributes, method of—Method of measuring quality that consists of noting the presence (or absence) of some characteristic (attribute) in each of the units under consideration and counting how many units do (or do not) possess it. Example: go/no-go gauging of a dimension.

audit—The on-site verification activity, such as inspection or examination, of a product, process, or quality system, to ensure compliance to requirements. An audit can apply to an entire organization or might be specific to a product, function, process, or production step.

Automotive Industry Action Group (AIAG)—A global automotive trade association with about 1600 member companies that focuses on common business processes, implementation guidelines, education, and training.

average chart—A control chart in which the subgroup average, $\bar{x}$, is used to evaluate the stability of the process level.

average outgoing quality (AOQ)—The expected average quality level of an outgoing product for a given value of incoming product quality.

average outgoing quality limit (AOQL)—The maximum average outgoing quality over all possible levels of incoming quality for a given acceptance sampling plan and disposal specification.

average run length (ARL)—On a control chart, the number of subgroups expected to be inspected before a shift in magnitude takes place.

average sample number (ASN)—The average number of sample units inspected per lot when reaching decisions to accept or reject.

average total inspection (ATI)—The average number of units inspected per lot, including all units in rejected lots. Applicable when the procedure calls for 100 percent inspection of rejected lots.

B

balanced scorecard—A management system that provides feedback on both internal business processes and external outcomes to continuously improve strategic performance and results.

Baldrige Award—See *Malcolm Baldrige National Quality Award*.

baseline measurement—The beginning point, based on an evaluation of output over a period of time, used to determine the process parameters prior to any improvement effort; the basis against which change is measured.

batch and queue—Producing more than one piece and then moving the pieces to the next operation before they are needed.

Bayes's theorem—A formula to calculate conditional probabilities by relating the conditional and marginal probability distributions of random variables.

benchmarking—A technique 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. Subjects that can be benchmarked include strategies, operations, and processes.

benefit–cost analysis—An examination of the relationship between the monetary cost of implementing an improvement and the monetary value of the benefits achieved by the improvement, both within the same time period.

bias—The influence in a sample of a factor that causes the data population or process being sampled to appear different from what it actually is, typically in a specific direction.[3]

binomial distribution—A discrete distribution that is applicable whenever an experiment consists of *n* independent Bernoulli trials and the probability of an outcome, say, success, is constant throughout the experiment.[1]

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 a business to drive up customer satisfaction and productivity levels.

block diagram—A diagram that shows the operation, interrelationships, and interdependencies of components in a system. Boxes, or blocks (hence the name), represent the components; connecting lines between the blocks represent interfaces. There are two types of block diagrams: a *functional block diagram*, which shows a system's subsystems and lower-level products and their interrelationships and which interfaces with other systems; and a *reliability block diagram*, which is similar to the functional block diagram but is modified to emphasize those aspects influencing reliability.

brainstorming—A technique teams use to generate ideas on a particular subject. Each person on the team is asked to think creatively and write down as many ideas as possible. The ideas are not discussed or reviewed until after the brainstorming session.

breakthrough improvement—A dynamic, decisive movement to a new, higher level of performance.

business process reengineering (BPR)—The concentration on improving business processes to deliver outputs that will achieve results meeting the firm's objectives, priorities, and mission.

C

calibration—The comparison of a measurement instrument or system of unverified accuracy to a measurement instrument or system of known accuracy to detect any variation from the required performance specification.

capability—The total range of inherent variation in a stable process determined by using data from control charts.

causation—The relationship between two variables. The changes in variable x cause changes in y. For example, a change in outdoor temperature causes changes in natural gas consumption for heating. If we can change x, we can bring about a change in y.

cause—An identified reason for the presence of a defect, problem, or effect.

cause-and-effect diagram—A tool for analyzing process dispersion. It is also referred to as the "Ishikawa diagram," because Kaoru Ishikawa developed it, and the "fishbone diagram," because the completed diagram resembles a fish skeleton. The diagram illustrates the main causes and subcauses leading to an effect (symptom). The cause-and-effect diagram is one of the "seven tools of quality."

***c*-chart**—See *count chart*.

centerline—A line on a graph that represents the overall average (mean) operating level of the process.

central limit theorem—A theorem that states that irrespective of the shape of the distribution of a population, the distribution of sample means is approximately normal when the sample size is large.[1]

central tendency—The tendency of data gathered from a process to cluster toward a middle value somewhere between the high and low values of measurement.

certification—The result of a person meeting the established criteria set by a certificate granting organization.

Certified Six Sigma Black Belt (CSSBB)—An ASQ certification.

Certified Six Sigma Green Belt (CSSGB)—An ASQ certification.

Certified Six Sigma Yellow Belt (CSSYB)—An ASQ certification.

chain reaction—A chain of events described by W. Edwards Deming: improve quality, decrease costs, improve productivity, increase market share with better quality and lower price, stay in business, provide jobs, and provide more jobs.

chain sampling plan—In acceptance sampling, a plan in which the criteria for acceptance and rejection apply to the cumulative sampling results for the current lot and one or more immediately preceding lots.

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

change agent—An individual from within or outside an organization who facilitates change in the organization; might be the initiator of the change effort, but not necessarily.

changeover—A process in which a production device is assigned to perform a different operation or a machine is set up to make a different part—for example, a new plastic resin and new mold in an injection molding machine.

changeover time—The time required to modify a system or workstation, usually including both teardown time for the existing condition and setup time for the new condition.

characteristic—The factors, elements, or measures that define and differentiate a process, function, product, service, or other entity.

chart—A tool for organizing, summarizing, and depicting data in graphic form.

charter—A written commitment approved by management stating the scope of authority for an improvement project or team.

check sheet—A simple data recording device. The check sheet is custom-designed by the user, which allows him or her to readily interpret the results. The check sheet is one of the "seven tools of quality."

checklist—A tool for ensuring that all important steps or actions in an operation have been taken. Checklists contain items important or relevant to an issue or situation. Checklists are often confused with check sheets.

chi-square distribution—Probability distribution of sum of squares of *n* independent normal variables.[1]

classification of defects—The listing of possible defects of a unit, classified according to their seriousness. Note: Commonly used classifications: class A, class B, class C, class D; or critical, major, minor, and incidental; or critical, major, and minor. Definitions of these classifications require careful preparation and tailoring to the product(s) being sampled to ensure accurate assignment of a defect to the proper classification. A separate acceptance sampling plan is generally applied to each class of defects.

common causes—Causes of variation that are inherent in a process over time. They affect every outcome of the process and everyone working in the process. (AKA *chance causes.*) Also see *special causes.*

compliance—The state of an organization that meets prescribed specifications, contract terms, regulations, or standards.

conformance—An affirmative indication or judgment that a product or service has met the requirements of a relevant specification, contract, or regulation.

conformity assessment—All activities concerned with determining that relevant requirements in standards or regulations are fulfilled, including sampling, testing, inspection, certification, management system assessment and registration, accreditation of the competence of those activities, and recognition of an accreditation program's capability.

constraint—Anything that limits a system from achieving higher performance or throughput; also, the bottleneck that most severely limits the organization's ability to achieve higher performance relative to its purpose or goal.

consumer—The external customer to whom a product or service is ultimately delivered; also called end user.

continuous (variables) data—Data that vary with discontinuity across an interval. The values of continuous data are often represented by floating point numbers. In sampling, continuous data are often referred to as variables data.[3]

continuous flow production—A method in which items are produced and moved from one processing step to the next, one piece at a time. Each process makes only the one piece that the next process needs, and the transfer batch size is one. Also referred to as *one-piece flow* and *single-piece flow*.

continuous improvement (CI)—Sometimes called *continual improvement*. The ongoing improvement of products, services, or processes through incremental and breakthrough improvements.

continuous quality improvement (CQI)—A philosophy and attitude for analyzing capabilities and processes and improving them repeatedly to achieve customer satisfaction.

continuous sampling plan—In acceptance sampling, a plan, intended for application to a continuous flow of individual units of product, that involves acceptance and rejection on a unit-by-unit basis and employs alternate periods of 100 percent inspection and sampling. The relative amount of 100 percent inspection depends on the quality of submitted product. Continuous sampling plans usually require that each *t* period of 100 percent inspection be continued until a specified number *i* of consecutively inspected units is found clear of defects. Note: For single-level continuous sampling plans, a single *d* sampling rate (for example, inspect one unit in five or one unit in 10) is used during sampling. For multilevel continuous sampling plans, two or more sampling rates can be used. The rate at any given time depends on the quality of submitted product.

control chart—A chart with upper and lower control limits on which values of some statistical measure for a series of samples or subgroups are plotted. The chart frequently shows a central line to help detect a trend of plotted values toward either control limit.

control limits—The natural boundaries of a process within specified confidence levels, expressed as the upper control limit (UCL) and the lower control limit (LCL).

control plan (CP)—Written description of the systems for controlling part and process quality by addressing the key characteristics and engineering requirements.

corrective action—A solution meant to reduce or eliminate an identified problem.

corrective action recommendation (CAR)—The full cycle corrective action tool that offers ease and simplicity for employee involvement in the corrective action/process improvement cycle.

correlation (statistical)—A measure of the relationship between two data sets of variables.

cost of poor quality (COPQ)—The costs associated with providing poor-quality products or services. There are four categories: internal failure costs (costs associated with defects found before the customer receives the product or service), external failure costs (costs associated with defects found after the customer receives the product or service), appraisal costs (costs incurred to determine the degree of conformance to quality requirements), and prevention costs (costs incurred to keep failure and appraisal costs to a minimum).

cost of quality (COQ)—Another term for COPQ. It is considered by some to be synonymous with COPQ but is considered by others to be unique. While the two concepts emphasize the same ideas, some disagree as to which concept came first and which categories are included in each.

count chart—A control chart for evaluating the stability of a process in terms of the count of events of a given classification occurring in a sample; known as a "*c*-chart."

count per unit chart—A control chart for evaluating the stability of a process in terms of the average count of events of a given classification per unit occurring in a sample.

C_p—The ratio of tolerance to six sigma, or the upper specification limit (USL) minus the lower specification limit (LSL) divided by six sigma. It is sometimes referred to as the engineering tolerance divided by the natural tolerance and is only a measure of dispersion.

C_{pk} index—Equals the lesser of the USL minus the mean divided by three sigma (or the mean) minus the LSL divided by three sigma. The greater the C_{pk} value, the better.

C_{pm}—Used when a target value within the specification limits is more significant than overall centering.[3]

critical path method (CPM)—An activity-oriented project management technique that uses arrow-diagramming techniques to demonstrate both the time and the cost required to complete a project. It provides one time estimate: normal time.

critical to quality (CTQ)—A characteristic of a product or service that is essential to ensure customer satisfaction.[2]

cumulative sum control chart (CUSUM)—A control chart on which the plotted value is the cumulative sum of deviations of successive samples from a target value. The ordinate of each plotted point represents the algebraic sum of the previous ordinate and the most recent deviations from the target.

customer relationship management (CRM)—A strategy for learning more about customers' needs and behaviors to develop stronger relationships with them. It brings together information about customers, sales, marketing effectiveness, responsiveness, and market trends. It helps businesses use technology and human resources to gain insight into the behavior of customers and the value of those customers.

customer satisfaction—The result of delivering a product or service that meets customer requirements.

cycle time—The time required to complete one cycle of an operation. If cycle time for every operation in a complete process can be reduced to equal takt time, products can be made in single-piece flow. Also see *takt time*.

cyclical variation—Looks at the piece-to-piece changes in consecutive order. Patterns are identified in groups, batches, or lots of units.[3]

D

data—A set of collected facts. There are two basic kinds of numerical data: measured or variables data, such as "16 ounces," "4 miles," and "0.75 inches," and counted or attributes data, such as "go/no go" or "yes/no."

D-chart—See *demerit chart*.

decision matrix—A matrix teams use to evaluate problems or possible solutions. For example, a team might draw a matrix to evaluate possible solutions, listing them in the far left vertical column. Next, the team selects criteria to rate the possible solutions, writing them across the top row. Then, each possible solution is rated on a scale of 1 to 5 for each criterion, and the rating is recorded in the corresponding grid. Finally, the ratings of all the criteria for each possible solution are added to determine its total score. The total score is then used to help decide which solution deserves the most attention.

defect—A product's or service's nonfulfillment of an intended requirement or reasonable expectation for use, including safety considerations. There are four classes of defects: class 1, very serious, leads directly to severe injury or catastrophic economic loss; class 2, serious, leads directly to significant injury or significant economic loss; class 3, major, is related to major problems with respect to intended normal or reasonably foreseeable use; and class 4, minor, is related to minor problems with respect to intended normal or reasonably foreseeable use.

defective—A defective unit; a unit of product that contains one or more defects with respect to the quality characteristic(s) under consideration.

demerit chart—A control chart for evaluating a process in terms of a demerit (or quality score); in other words, a weighted sum of counts of various classified nonconformities.

Deming cycle—Another term for the plan–do–study–act cycle. Walter Shewhart created it (calling it the plan–do–check–act cycle), but W. Edwards Deming popularized it, calling it plan–do–study–act.

dependability—The degree to which a product is operable and capable of performing its required function at any randomly chosen time during its specified operating time, provided that the product is available at the start of that period. (Nonoperation related influences are not included.) Dependability can be expressed by the following ratio: time available divided by (time available + time required).

design for Six Sigma (DFSS)—Used for developing a new product or process, or for processes that need total overhaul. A process often used in DFSS is called DMADV: define, measure, analyze, design, verify.[4] See also *DMADV*.

design of experiments (DOE)—A branch of applied statistics dealing with planning, conducting, analyzing, and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters.

design record—Engineering requirements, typically contained in various formats; examples include engineering drawings, math data, and referenced specifications.

deviation—In numerical data sets, the difference or distance of an individual observation or data value from the center point (often the mean) of the set distribution.

dissatisfiers—The features or functions a customer expects that either are not present or are present but not adequate; also pertains to employees' expectations.

distribution (statistical)—The amount of potential variation in the outputs of a process, typically expressed by its shape, average, or standard deviation.

DMADV—A data-driven quality strategy for designing products and processes; it is an integral part of a Six Sigma quality initiative. It consists of five interconnected phases: define, measure, analyze, design, and verify.

DMAIC—A data-driven quality strategy for improving processes, and an integral part of a Six Sigma quality initiative. DMAIC is an acronym for define, measure, analyze, improve, and control.

Dodge-Romig sampling plans—Plans for acceptance sampling developed by Harold F. Dodge and Harry G. Romig. Four sets of tables were published in 1940: single sampling lot tolerance tables, double sampling lot tolerance tables, single sampling average outgoing quality limit tables, and double sampling average outgoing quality limit tables.

downtime—Lost production time during which a piece of equipment is not operating correctly due to breakdown, maintenance, power failures, or similar events.

E

effect—The result of an action being taken; the expected or predicted impact when an action is to be taken or is proposed.

effectiveness—The state of having produced a decided on or desired effect.

efficiency—The ratio of the output to the total input in a process.

efficient—A term describing a process that operates effectively while consuming minimal resources (such as labor and time).

eight wastes—Taiichi Ohno originally enumerated seven wastes (muda) and later added *underutilized people* as the eighth waste commonly found in physical production. The eight are (1) overproduction ahead of demand, (2) waiting for the next process, worker, material, or equipment, (3) unnecessary transport of materials (for example, between functional areas of facilities, or to or from a stockroom or warehouse), (4) overprocessing of parts due to poor tool and product design, (5) inventories more than the absolute minimum, (6) unnecessary movement by employees during the course of their work (such as to look for parts, tools, prints, or help), (7) production of defective parts, (8) underutilization of employees' brainpower, skills, experience, and talents.

eighty–twenty (80–20)—A term referring to the Pareto principle, which was first defined by J. M. Juran in 1950. The principle suggests that most effects come from relatively few causes; that is, 80 percent of the effects come from 20 percent of the possible causes. Also see *Pareto chart*.

enumerative (descriptive) studies—A group of methods used for organizing, summarizing, and representing data using tables, graphs, and summary statistics.[1]

error detection—A hybrid form of error-proofing. It means a bad part can be made but will be caught immediately, and corrective action will be taken to prevent another bad part from being produced. A device is used to detect and stop the process when a bad part is made. This is used when error-proofing is too expensive or not easily implemented.

error-proofing—Use of process or design features to prevent the acceptance or further processing of nonconforming products. Also known as *mistake-proofing*.

experimental design—A formal plan that details the specifics for conducting an experiment, such as which responses, factors, levels, blocks, treatments, and tools are to be used.

external customer—A person or organization that receives a product, service, or information but is not part of the organization supplying it. Also see *internal customer*.

external failure—Nonconformance identified by the external customers.

F

failure—The inability of an item, product, or service to perform required functions on demand due to one or more defects.

failure cost—The cost resulting from the occurrence of defects. One element of cost of quality or cost of poor quality.

failure mode analysis (FMA)—A procedure to determine which malfunction symptoms appear immediately before or after a failure of a critical parameter in a system. After all possible causes are listed for each symptom, the product is designed to eliminate the problems.

failure mode and effects analysis (FMEA)—A systematized group of activities to recognize and evaluate the potential failure of a product or process and its effects, identify actions that could eliminate or reduce the occurrence of the potential failure, and document the process.

***F*-distribution**—A continuous probability distribution of the ratio of two independent chi-square random variables.[1]

first in, first out (FIFO)—Use of material produced by one process in the same order by the next process. A FIFO queue is filled by the supplying process and emptied by the customer process. When a FIFO lane gets full, production is stopped until the next (internal) customer has used some of that inventory.

first-pass yield (FPY)—Also referred to as the *quality rate*, the percentage of units that completes a process and meets quality guidelines without being scrapped, rerun, retested, returned, or diverted into an offline repair area. FPY is calculated by dividing the units entering the process minus the defective units by the total number of units entering the process.

first-time quality (FTQ)—Calculation of the percentage of good parts at the beginning of a production run.

fishbone diagram—See *cause-and-effect diagram*.

fitness for use—A term used to indicate that a product or service fits the customer's defined purpose for that product or service.

five S (5S)—Five Japanese terms beginning with "s" used to create a workplace suited for visual control and lean production. *Seiri* means to separate needed tools, parts, and instructions from unneeded materials and to remove the unneeded ones. *Seiton* means to neatly arrange and identify parts and tools for ease of use. *Seiso* means to conduct a cleanup campaign. *Seiketsu* means to conduct seiri, seiton, and seiso daily to maintain a workplace in perfect condition. *Shitsuke* means to form the habit of always following the first four S's.

five whys—A technique for discovering the root causes of a problem and showing the relationship of causes by repeatedly asking the question, "Why?"

flow—The progressive achievement of tasks along the value stream so a product proceeds from design to launch, order to delivery, and raw to finished materials in the hands of the customer with no stoppages, scrap, or backflows.

flowchart—A graphical representation of the steps in a process. Flowcharts are drawn to better understand processes. One of the "seven tools of quality."

force-field analysis—A technique for analyzing what aids or hinders an organization in reaching an objective. An arrow pointing to an objective is drawn down the middle of a piece of paper. The factors that will aid the objective's achievement, called the driving forces, are listed on the left side of the arrow. The factors that will hinder its achievement, called the restraining forces, are listed on the right side of the arrow.

G

gage repeatability and reproducibility (GR&R)—The evaluation of a gauging instrument's accuracy by determining whether its measurements are repeatable (there is close agreement among a number of consecutive measurements of the output for the same value of the input under the same operating conditions) and reproducible (there is close agreement among repeated measurements of the output for the same value of input made under the same operating conditions over a period of time).

Gantt chart—A type of bar chart used in process planning and control to display planned and finished work in relation to time.

geometric dimensioning and tolerancing (GD&T)—A set of rules and standard symbols to define part features and relationships on an engineering drawing depicting the geometric relationship of part features and allowing the maximum tolerance that permits full function of the product.

go/no-go—State of a unit or product. Two parameters are possible: go (conforms to specifications) and no-go (does not conform to specifications).

Green Belt (GB)—An employee who has been trained in the Six Sigma improvement method at a Green Belt level and will lead a process improvement or quality improvement team as part of his or her full-time job.

H

Hawthorne effect—The concept that every change results (initially, at least) in increased productivity.

heijunka—A method of leveling production, usually at the final assembly line, that makes just-in-time production possible. It involves averaging both the volume and sequence of different model types on a mixed-model production line. Using this method avoids excessive batching of different types of product and volume fluctuations in the same product.

histogram—A graphic summary of variation in a set of data. The pictorial nature of a histogram lets people see patterns that are difficult to detect in a simple table of numbers. One of the "seven tools of quality."

hoshin kanri—The selection of goals, projects to achieve the goals, designation of people and resources for project completion, and establishment of project metrics.

hoshin planning—Breakthrough planning. A Japanese strategic 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 submitted audits are then conducted to monitor progress. Also see *value stream*.

house of quality—A product planning matrix, somewhat resembling a house, that is developed during quality function deployment and shows the relationship of customer requirements to the means of achieving these requirements.

I

in-control process—A process in which the statistical measure being evaluated is in a state of statistical control; in other words, the variations among the observed sampling results can be attributed to a constant system of chance causes (common causes). Also see *out-of-control process*.

incremental improvement—Improvement implemented on a continual basis.

indicators—Established measures to determine how well an organization is meeting its customers' needs and other operational and financial performance expectations.

inputs—The products, services, and material obtained from suppliers to produce the outputs delivered to customers.

inspection—Measuring, examining, testing, and gauging one or more characteristics of a product or service and comparing the results with specified requirements to determine whether conformity is achieved for each characteristic.

inspection, normal—Inspection used in accordance with a sampling plan under ordinary circumstances.

inspection, 100 percent—Inspection of all the units in the lot or batch.

inspection cost—The cost associated with inspecting a product to ensure that it meets the internal or external customer's needs and requirements; an appraisal cost.

inspection lot—A collection of similar units or a specific quantity of similar material offered for inspection and acceptance at one time.

internal customer—The recipient (person or department) within an organization of another person's or department's output (product, service, or information). Also see *external customer.*

internal failure—A product failure that occurs before the product is delivered to external customers.

International Organization for Standardization—A network of national standards institutes from 157 countries working in partnership with international organizations, governments, industry, business, and consumer representatives to develop and publish international standards; acts as a bridge between public and private sectors.

interrelationship diagram—A management tool that depicts the relationship among factors in a complex situation; also called a *relations diagram.*

Ishikawa diagram—See *cause-and-effect diagram.*

J

jidoka—The deliberate effort to automate a process with a human touch. It means that when a problem occurs on a production line, a worker or machine is able to stop the process and prevent defective goods from being produced.

just-in-time (JIT) manufacturing—An optimal material requirement planning system for a manufacturing process in which there is little or no manufacturing material inventory on hand at the manufacturing site and little or no incoming inspection.

K

kaizen—A Japanese term that means gradual unending improvement by doing little things better and setting and achieving increasingly higher standards. Masaaki Imai made the term famous in his book *Kaizen: The Key to Japan's Competitive Success*.

kanban—A Japanese term for one of the primary tools of a just-in-time system. It maintains an orderly and efficient flow of materials throughout the entire manufacturing process. It is usually a printed card that contains specific information such as part name, description, and quantity.

key performance indicator (KPI)—A statistical measure of how well an organization is doing in a particular area. A KPI could measure a company's financial performance or how it is holding up against customer requirements.

key process characteristic—A process parameter that can affect safety or compliance with regulations, fit, function, performance, or subsequent processing of product.

key product characteristic—A product characteristic that can affect safety or compliance with regulations, fit, function, performance, or subsequent processing of product.

L

leadership—An essential part of a quality improvement effort. Organization leaders must establish a vision, communicate that vision to those in the organization, and provide the tools and knowledge necessary to accomplish the vision.

lean—Producing the maximum sellable products or services at the lowest operational cost while optimizing inventory levels and eliminating waste.

lean enterprise—A manufacturing company organized to eliminate all unproductive effort and unnecessary investment, both on the shop floor and in office functions.

lean manufacturing/production—An initiative focused on eliminating all waste in manufacturing processes. Principles of lean manufacturing include zero waiting time, zero inventory, scheduling (internal customer pull instead of push system), batch to flow (cut batch sizes), line balancing, and cutting actual process times. The production systems are characterized by optimum automation, just-in-time supplier delivery disciplines, quick changeover times, high levels of quality, and continuous improvement.

lean migration—The journey from traditional manufacturing methods to one in which all forms of waste are systematically eliminated.

linearity—Refers to measurements being statistically different from one end of the measurement space to the other. For example, a measurement process may be very capable of measuring small parts but much less accurate measuring large parts, or one end of a long part can be measured more accurately than the other.[3]

lot—A defined quantity of product accumulated under conditions considered uniform for sampling purposes.

lot, batch—A definite quantity of some product manufactured under conditions of production that are considered uniform.

lot quality—The value of percentage defective or of defects per hundred units in a lot.

lot size (also referred to as *N*)—The number of units in a lot.

lower control limit (LCL)—Control limit for points below the central line in a control chart.

M

maintainability—The probability that a given maintenance action for an item under given usage conditions can be performed within a stated time interval when the maintenance is performed under stated conditions using stated procedures and resources.

Malcolm Baldrige National Quality Award (MBNQA)—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. Awards can be given annually in six categories: manufacturing, service, small business, education, healthcare, and nonprofit. 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.

Master Black Belt (MBB)—Six Sigma or quality expert responsible for strategic implementations in an organization. An MBB is qualified to teach other Six Sigma facilitators the methods, tools, and applications in all functions and levels of the company, and is a resource for using statistical process control in processes.

matrix diagram—A planning tool for displaying the relationships among various data sets.

mean—A measure of central tendency; the arithmetic average of all measurements in a data set.

mean time between failures (MTBF)—The average time interval between failures for repairable product for a defined unit of measure; for example, operating hours, cycles, and miles.

measure—The criteria, metric, or means to which a comparison is made with output.

measurement—The act or process of quantitatively comparing results with requirements.

median—The middle number or center value of a set of data in which all the data are arranged in sequence.

metric—A standard for measurement.

MIL-STD-105E—A military standard that describes the sampling procedures and tables for inspection by attributes.

mistake-proofing—Use of production or design features to prevent the manufacture or passing downstream of a nonconforming product; also known as *error-proofing*.

mode—The value occurring most frequently in a data set.

muda—Japanese for *waste*; any activity that consumes resources but creates no value for the customer.

multivariate control chart—A control chart for evaluating the stability of a process in terms of the levels of two or more variables or characteristics.

multivoting—Typically used after brainstorming, multivoting narrows a large list of possibilities to a smaller list of the top priorities (or to a final selection) by allowing items to be ranked in importance by participants. Multivoting is preferable to straight voting because it allows an item that is favored by all, but not the top choice of any, to rise to the top.[4]

N

n—The number of units in a sample.

N—The number of units in a population.

nominal group technique (NGT)—A technique, similar to brainstorming, used to generate ideas on a particular subject. Team members are asked to silently write down as many ideas as possible. Each member is then asked to share one idea, which is recorded. After all the ideas are recorded, they are discussed and prioritized by the group.

nonconformity—The nonfulfillment of a specified requirement.

nondestructive testing and evaluation (NDT, NDE)—Testing and evaluation methods that do not damage or destroy the product being tested.

nonlinear parameter estimation—A method whereby the arduous and labor-intensive task of multiparameter model calibration can be carried out automatically under the control of a computer.

nonparametric tests—All tests involving ranked data (data that can be put in order). Nonparametric tests are often used in place of their parametric counterparts when certain assumptions about the underlying population are questionable. For example, when comparing two independent samples, the Wilcoxon Mann-Whitney test (see entry) does not assume that the difference between the samples is normally distributed, whereas its parametric counterpart, the two-sample *t*-test, does. Nonparametric tests can be, and often are, more powerful in detecting population differences when certain assumptions are not satisfied.

non-value-added—A term that describes a process step or function that is not required for the direct achievement of process output. This step or function is identified and examined for potential elimination. Also see *value-added*.

normal distribution (statistical)—The charting of a data set in which most of the data points are concentrated around the average (mean), thus forming a bell-shaped curve.

O

operating characteristic curve (OC curve)—A graph to determine the probability of accepting lots as a function of the lots' or processes' quality level when using various sampling plans. There are three types: type A curves, which give the probability of acceptance for an individual lot coming from finite production (will not continue in the future); type B curves, which give the probability of acceptance for lots coming from a continuous process; and type C curves, which (for a continuous sampling plan) give the long-run percentage of product accepted during the sampling phase.

operations—Work or steps to transform raw materials to finished product.

out of spec—A term that indicates a unit does not meet a given requirement or specification.

out-of-control process—A process in which the statistical measure being evaluated is not in a state of statistical control. In other words, the variations among the observed sampling results cannot be attributed to a constant system of chance causes. Also see *in-control process*.

outputs—Products, materials, services, or information provided to customers (internal or external), from a process.

P

paired-comparison tests—Examples are two-mean, equal variance t-test; two-mean, unequal variance t-test; paired t-test; and F-test.

Pareto chart—A graphical tool for ranking causes from most significant to least significant. It is based on the Pareto principle, which was first defined by Joseph M. Juran in 1950. The principle, named after 19th-century economist Vilfredo Pareto, suggests that most effects come from relatively few causes; that is, 80 percent of the effects come from 20 percent of the possible causes. One of the "seven tools of quality."

parts per million (ppm)—A method of stating the performance of a process in terms of actual nonconforming material, which can include rejected, returned, or suspect material in the calculation.

***p*-chart**—See *percent chart*.

percent chart—A control chart for evaluating the stability of a process in terms of the percentage of the total number of units in a sample in which an event of a given classification occurs. Also referred to as a *proportion chart*.

plan–do–check–act (PDCA) cycle—A four-step process for quality improvement. In the first step (plan), a way to effect improvement is developed. In the second step (do), the plan is carried out, preferably on a small scale. In the third step (check), a study takes place comparing what was predicted and what was observed in the previous step. In the last step (act), action is taken on the causal system to effect the desired change. The plan–do–check–act cycle is sometimes referred to as the Shewhart cycle, because Walter A. Shewhart discussed the concept in his book *Statistical Method from the Viewpoint of Quality Control*, and as the Deming cycle, because W. Edwards Deming introduced the concept in Japan. The Japanese subsequently called it the Deming cycle. Also called the *plan–do–study–act (PDSA) cycle*.

point of use—A technique that ensures people have exactly what they need to do their jobs—work instructions, parts, tools, and equipment—where and when they need them.

Poisson distribution—A discrete probability distribution that expresses the probability of a number of events occurring in a fixed time period if these events occur with a known average rate and are independent of the time since the last event.

poka-yoke—Japanese term that means mistake-proofing. A poka-yoke device is one that prevents incorrect parts from being made or assembled, or easily identifies a flaw or error.

positional variation—Type of variation frequently within-piece, but can also include machine-to-machine variation, line-to-line or plant-to-plant variation, within-batch variation, and test positioning variation.[3]

P_p (process performance index)—An index describing process performance in relation to specified tolerance.[2]

P_{pk} (minimum process performance index)—The smaller of upper process performance index and lower process performance index.[2]

practical significance—At least as important as the question of statistical significance, practical or economic significance determines whether an observed sample difference is large enough to be of practical interest.

precision—The aspect of measurement that addresses repeatability or consistency when an identical item is measured several times.

prevention cost—The cost incurred by actions taken to prevent a nonconformance from occurring; one element of cost of quality or cost of poor quality.

preventive action—Action taken to remove or improve a process to prevent potential future occurrences of a nonconformance.

prioritization matrix—An L-shaped matrix that uses pairwise comparisons of a list of options to a set of criteria in order to choose the best option(s). First, the importance of each criterion is decided. Then, each criterion is considered separately, with each option rated for how well it meets the criterion. Finally, all the ratings are combined for a final ranking of options. Numerical calculations ensure a balance between the relative importance of the criteria and the relative merits of the options.[4]

probability (statistical)—The likelihood of occurrence of an event, action, or item.

procedure—The steps in a process and how these steps are to be performed for the process to fulfill a customer's requirements; usually documented.

process—A set of interrelated work activities characterized by a set of specific inputs and value-added tasks that make up a procedure for a set of specific outputs.

process average quality—Expected or average value of process quality.

process capability—A statistical measure of the inherent process variability of a given characteristic. The most widely accepted formula for process capability is Six Sigma.

process capability index—The value of the inherent tolerance specified for the characteristic divided by the process capability. The several types of process capability indices include the widely used C_{pk} and C_p.

process control—The method for keeping a process within boundaries; the act of minimizing the variation of a process.

process decision program charts (PDPC)—A variant of tree diagrams, a PDPC can be used as a simple alternative to FMEA.[3]

process flow diagram—A depiction of the flow of materials through a process, including any rework or repair operations; also called a *process flow chart*.

process improvement—The application of the plan–do–check–act cycle (see entry) to processes to produce positive improvement and better meet the needs and expectations of customers.

process management—The pertinent techniques and tools applied to a process to implement and improve process effectiveness, hold the gains, and ensure process integrity in fulfilling customer requirements.

process map—A type of flowchart depicting the steps in a process and identifying responsibility for each step and key measures.

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.

process performance management—The overseeing of process instances to ensure their quality and timeliness; can also include proactive and reactive actions to ensure a good result.

process quality—The value of percentage defective or of defects per hundred units in product from a given process. Note: The symbols "*p*" and "*c*" are commonly used to represent the true process average in fraction defective or defects per unit, and "100p" and "100c" the true process average in percentage defective or in defects per hundred units.

production part approval process (PPAP)—A "Big Three" automotive process that defines the generic requirements for approval of production parts, including production and bulk materials. Its purpose is to determine during an actual production run at the quoted production rates whether all customer engineering design record and specification requirements are properly understood by the supplier and that the process has the potential to produce product consistently meeting these requirements.

program evaluation and review technique (PERT) charts—Developed during the Nautilus submarine program in the 1950s, a PERT chart resembles an activity network diagram in that it shows task dependencies. It calculates best, average, and worst expected completion times.[3]

project management—The application of knowledge, skills, tools, and techniques to a broad range of activities to meet the requirements of a particular project.

project team—Manages the work of a project. The work typically involves balancing competing demands for project scope, time, cost, risk, and quality, satisfying stakeholders with differing needs and expectations, and meeting identified requirements.

proportion chart—See *percent chart*.

pull system—An alternative to scheduling individual processes in which the customer process withdraws the items it needs as at a supermarket, and the supplying process produces to replenish what was withdrawn; used to avoid push. Also see *kanban*.

Q

quality—A subjective term for which each person or sector has its own definition. In technical usage, quality can have two meanings: 1. the characteristics of a product or service that bear on its ability to satisfy stated or implied needs; 2. a product or service free of deficiencies. According to Joseph M. Juran, quality means "fitness for use"; according to Philip Crosby, it means "conformance to requirements."

quality assurance/quality control (QA/QC)—Two terms that have many interpretations because of the multiple definitions for the words "assurance" and "control." For example, "assurance" can mean the act of giving confidence, the state of being certain, or the act of making certain; "control" can mean an evaluation to indicate needed corrective responses, the act of guiding, or the state of a process in which the variability is attributable to a constant system of chance causes. (For a detailed discussion on the multiple definitions, see ANSI/ISO/ASQ A3534-2, *Statistics—Vocabulary and symbols—Statistical quality control*.) One definition of quality assurance is: all the planned and systematic activities implemented within the quality system that can be demonstrated to provide confidence that a product or service will fulfill requirements for quality. One definition for quality control is: the operational techniques and activities used to fulfill requirements for quality. Often, however, "quality assurance" and "quality control" are used interchangeably, referring to the actions performed to ensure the quality of a product, service, or process.

quality audit—A systematic, independent examination and review to determine whether quality activities and related results comply with plans and whether these plans are implemented effectively and are suitable to achieve the objectives.

quality costs—See *cost of poor quality.*

quality function deployment (QFD)—A structured method in which customer requirements are translated into appropriate technical requirements for each stage of product development and production. The QFD process is often referred to as listening to the voice of the customer.

quality loss function—A parabolic approximation of the quality loss that occurs when a quality characteristic deviates from its target value. The quality loss function is expressed in monetary units: the cost of deviating from the target increases quadratically the farther the quality characteristic moves from the target. The formula used to compute the quality loss function depends on the type of quality characteristic being used. The quality loss function was first introduced in this form by Genichi Taguchi.

quality management (QM)—The application of a quality management system in managing a process to achieve maximum customer satisfaction at the lowest overall cost to the organization while continuing to improve the process.

quality management system (QMS)—A formalized system that documents the structure, responsibilities, and procedures required to achieve effective quality management.

queue time—The time a product spends in a line awaiting the next design, order processing, or fabrication step.

quick changeover—The ability to change tooling and fixtures rapidly (usually within minutes) so multiple products can be run on the same machine.

R

random cause—A cause of variation due to chance and not assignable to any factor.

random sampling—A commonly used sampling technique in which sample units are selected so all combinations of n units under consideration have an equal chance of being selected as the sample.

range (statistical)—The measure of dispersion in a data set (the difference between the highest and lowest values).

range chart (R chart)—A control chart in which the subgroup range R evaluates the stability of the variability within a process.

rational subgrouping—Subgrouping wherein the variation is presumed to be only from random causes.[2]

regression analysis—A statistical technique for determining the best mathematical expression describing the functional relationship between one response variable and one or more independent variables.

relations diagram—See *interrelationship diagram*.

reliability—The probability of a product's performing its intended function under stated conditions without failure for a given period of time.

repeatability—The variation in measurements obtained when one measurement device is used several times by the same person to measure the same characteristic on the same product.

reproducibility—The variation in measurements made by different people using the same measuring device to measure the same characteristic on the same product.

requirements—The ability of an item to perform a required function under stated conditions for a stated period of time.

risk management—Using managerial resources to integrate risk identification, risk assessment, risk prioritization, development of risk handling strategies, and mitigation of risk to acceptable levels.

risk priority number (RPN)—The product of the severity, occurrence, and detection values determined in FMEA. The higher the RPN, the more significant the failure mode.

robustness—The condition of a product or process design that remains relatively stable, with a minimum of variation, even though factors that influence operations or usage, such as environment and wear, are constantly changing.

root cause—A factor that caused a nonconformance and should be permanently eliminated through process improvement.

run chart—A chart showing a line connecting numerous data points collected from a process running over time.

S

sample—In acceptance sampling, one or more units of product (or a quantity of material) drawn from a lot for purposes of inspection to reach a decision regarding acceptance of the lot.

sample size (n)—The number of units in a sample.

sample standard deviation chart (s-chart)—A control chart in which the subgroup standard deviation s is used to evaluate the stability of the variability within a process.

scatter diagram—A graphical technique to analyze the relationship between two variables. Two sets of data are plotted on a graph, with the y-axis being used for the variable to be predicted and the *x*-axis being used for the variable to make the prediction. The graph will show possible relationships (although two variables might appear to be related, they might not be; those who know most about the variables must make that evaluation). One of the "seven tools of quality."

seven tools of quality—Tools that help organizations understand their processes to improve them. The tools are the cause-and-effect diagram, check sheet, control chart, flowchart, histogram, Pareto chart, and scatter diagram.

seven wastes—See *eight wastes.*

Shewhart cycle—See *plan–do–check–act cycle.*

sigma—One standard deviation in a normally distributed process.

single-piece flow—A process in which products proceed one complete product at a time, through various operations in design, order taking, and production without interruptions, backflows, or scrap.

SIPOC diagram—A tool used by Six Sigma process improvement teams to identify all relevant elements (suppliers, inputs, process, outputs, customers) of a process improvement project before work begins.

Six Sigma—A method that provides organizations tools to improve the capability of their business processes. This increase in performance and decrease in process variation lead to defect reduction and improvement in profits, employee morale, and quality of products or services. Six Sigma quality is a term generally used to indicate that a process is well controlled ($\pm6\sigma$ from the centerline in a control chart).

six sigma quality—A term generally used to indicate process capability in terms of process spread measured by standard deviations in a normally distributed process.

special causes—Causes of variation that arise because of special circumstances. They are not an inherent part of a process. Special causes are also referred to as *assignable causes.* Also see *common causes.*

specification—A document that states the requirements to which a given product or service must conform.

stages of team growth—Four stages that teams move through as they develop maturity: forming, storming, norming, and performing.

standard deviation (statistical)—A computed measure of variability indicating the spread of the data set around the mean.

standard work—A precise description of each work activity, specifying cycle time, takt time, the work sequence of specific tasks, and the minimum inventory of parts on hand needed to conduct the activity. All jobs are organized around human motion to create an efficient sequence without waste. Work organized in such a way is called standard(ized) work. The three elements that make up standard work are takt time, working sequence, and standard in-process stock.

standard work instructions—A lean manufacturing tool that enables operators to observe a production process with an understanding of how assembly tasks are to be performed. It ensures that the quality level is understood and serves as an excellent training aid, enabling replacement or temporary individuals to easily adapt and perform the assembly operation.

statistical process control (SPC)—The application of statistical techniques to control a process; often used interchangeably with the term *statistical quality control*.

statistical quality control (SQC)—The application of statistical techniques to control quality. Often used interchangeably with the term *statistical process control*, although statistical quality control includes acceptance sampling, which statistical process control does not.

statistical significance—Level of accuracy expected of an analysis of data. Most frequently it is expressed as either a "95 percent level of significance" or "five percent confidence level."[5]

strengths, weaknesses, opportunities, threats (SWOT) analysis—A strategic technique used to assess an organization's competitive position.

Student's *t*-distribution—A continuous distribution of the ratio of two independent random variables—a standard normal and a chi-square.[1]

supplier—A source of materials, service, or information input provided to a process.

supplier quality assurance—Confidence that a supplier's product or service will fulfill its customers' needs. This confidence is achieved by creating a relationship between the customer and supplier that ensures that the product will be fit for use with minimal corrective action and inspection. According to Joseph M. Juran, nine primary activities are needed: (1) define product and program quality requirements, (2) evaluate alternative suppliers, (3) select suppliers, (4) conduct joint quality planning, (5) cooperate with the supplier during the execution of the contract, (6) obtain proof of conformance to requirements, (7) certify qualified suppliers, (8) conduct quality improvement programs as required, (9) create and use supplier quality ratings.

supply chain—The series of suppliers to a given process.

system—A group of interdependent processes and people that together perform a common mission.

T

Taguchi methods—The American Supplier Institute's trademarked term for the quality engineering methodology developed by Genichi Taguchi. In this engineering approach to quality control, Taguchi calls for off-line quality control, online quality control, and a system of experimental design to improve quality and reduce costs.

takt time—The rate of customer demand, takt time is calculated by dividing production time by the quantity of product the customer requires in that time. Takt is the heartbeat of a lean manufacturing system. Also see *cycle time*.

team—A group of individuals organized to work together to accomplish a specific objective. Also see *stages of team growth*.

temporal variation—The time-to-time or shift-to-shift variation—that is, variation across time.[3]

theory of constraints (TOC)—A lean management philosophy that stresses removal of constraints to increase throughput while decreasing inventory and operating expenses. TOC's set of tools examines the entire system for continuous improvement. The current reality tree, conflict resolution diagram, future reality tree, prerequisite tree, and transition tree are the five tools used in TOC's ongoing improvement process. Also called *constraints management*.

throughput—The rate at which the system generates money through sales, or the conversion rate of inventory into shipped product.

tolerance—The maximum and minimum limit values a product can have and still meet customer requirements.

total productive maintenance (TPM)—A series of methods, originally pioneered by Nippondenso (a member of the Toyota group), to ensure that every machine in a production process is always able to perform its required tasks so production is never interrupted.

total quality management (TQM)—A term coined by the Naval Air Systems Command to describe its Japanese-style management approach to quality improvement. Since then, TQM has taken on many meanings. Simply put, it is a management approach to long-term success through customer satisfaction. TQM is based on all members of an organization participating in improving processes, products, services, and the culture in which they work. The methods for implementing this approach are found in the teachings of such quality leaders as Philip B. Crosby, W. Edwards Deming, Armand V. Feigenbaum, Kaoru Ishikawa, and Joseph M. Juran.

Toyota Production System (TPS)—The production system developed by Toyota Motor Corp. to provide best quality, lowest cost, and shortest lead time through eliminating waste. TPS is based on two pillars: just-in-time and jidoka. TPS is maintained and improved through iterations of standardized work and kaizen.

tree diagram—A management tool that depicts the hierarchy of tasks and subtasks needed to complete an objective. The finished diagram bears a resemblance to a tree.

trend—The graphical representation of a variable's tendency, over time, to increase, decrease, or remain unchanged.

trend control chart—A control chart in which the deviation of the subgroup average, $\bar{x}$, from an expected trend in the process level is used to evaluate the stability of a process.

TRIZ—A Russian acronym for a theory of innovative problem solving.

***t*-test**—A method to assess whether the means of two groups are statistically different from each other.

type I error—An incorrect decision to reject something (such as a statistical hypothesis or a lot of products) when it is acceptable.

type II error—An incorrect decision to accept something when it is unacceptable.

U

***u*-chart**—Count-per-unit chart.

unit—An object for which a measurement or observation can be made; commonly used in the sense of a "unit of product," the entity of product inspected to determine whether it is defective or nondefective.

upper control limit (UCL)—Control limit for points above the central line in a control chart.

V

validation—The act of confirming that a product or service meets the requirements for which it was intended.

validity—The ability of a feedback instrument to measure what it was intended to measure; also, the degree to which inferences derived from measurements are meaningful.

value stream—All activities, both value-added and non-value-added, required to bring a product from raw material state into the hands of the customer, bring a customer requirement from order to delivery, and bring a design from concept to launch. Also see *hoshin planning*.

value stream mapping—A pencil and paper tool used in two stages. First, follow a product's production path from beginning to end and draw a visual representation of every process in the material and information flows. Second, draw a future state map of how value should flow. The most important map is the future state map.

value-added—A term used to describe activities that transform input into a customer (internal or external)–usable output.

variables (attributes) data—Measurement information. Control charts based on variables data include average ($\bar{x}$) chart, range (R) chart, and sample standard deviation (s) chart.

variation—A change in data, characteristic, or function caused by one of four factors: special causes, common causes, tampering, or structural variation.

verification—The act of determining whether products and services conform to specific requirements.

voice of the customer—The expressed requirements and expectations of customers relative to products or services, as documented and disseminated to the providing organization's members.

W

waste—Any activity that consumes resources and produces no added value to the product or service a customer receives. Also known as *muda*.

Wilcoxon Mann-Whitney test—Used to test the null hypothesis that two populations have identical distribution functions against the alternative hypothesis that the two distribution functions differ only with respect to location (median), if at all. It does not require the assumption that the differences between the two samples are normally distributed. In many applications, it is used in place of the two-sample *t*-test when the normality assumption is questionable. This test can also be applied when the observations in a sample of data are ranks, that is, ordinal data, rather than direct measurements.

X

***x*-bar ($\bar{x}$) chart**—Average chart.

Z

zero defects—A performance standard and method Philip B. Crosby developed, which states that if people commit themselves to watching details and avoiding errors, they can move closer to the goal of zero defects.

Endnotes

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