THE ASQ CERTIFIED SIX SIGMA YELLOW BELT HANDBOOK

SECOND EDITION

GOVIND RAMU, Editor

The ASQ Certified Six Sigma Yellow Belt Handbook

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Govind Ramu

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I thank my mom, Vasantha, for her unconditional love and encouragement. My dad, Ramu, would have been so proud to see this book come out. The morals and principles that he taught me keep me grounded. Thanks to my wife, Anitha, and my children, Vibha and Vivek, for their patience and sacrifice of countless evenings and weekends. Without their support, this book would not have been possible.

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Preface

Welcome to *The* ASQ *Certified Six Sigma Yellow Belt Handbook*. This reference manual is designed to help both those interested in passing the certification exam of the American Society for Quality (ASQ) for the Six Sigma Yellow Belt and those who want a handy reference to the appropriate materials needed for successful Six Sigma projects. I have made a sincere attempt to make this book a reference for both beginners in Six Sigma and those who are already knowledgeable about process improvement and variation reduction.

The primary layout of the handbook follows ASQ's Body of Knowledge (BoK) for the Certified Six Sigma Yellow Belt (CSSYB) released in 2022. I have used feedback from Six Sigma practitioners and knowledge gained through helping others prepare for exams to create a handbook that I hope will be beneficial to anyone seeking to pass the ASQ CSSYB or other Six Sigma exams. In addition to the primary text, the handbook contains numerous appendices, a comprehensive list of abbreviations, and practice exam questions; Online Contents accompanying the book contain additional materials. A word of caution—you are not allowed to take any of the exam questions into the ASQ exam. While most ASQ certification exams use solely a multiple-choice question format (ASQ CMQ/OE and CSSMBB are exceptions), many users of ASQ handbooks on the academic side prefer essay-type questions for the chapters to test the comprehension of students using this book at colleges and universities. I would advise the ASQ exam takers to make a note of this but not be too concerned. The essay questions are included to challenge the users. The difficulty level of the essay questions is likely higher than that of the questions in the ASQ certification exam. Six Sigma trainers for organizations may find this additional feature useful, as they want their trainees (staff) to not only pass ASQ Six Sigma exams but have a comprehensive understanding of the Body of Knowledge that will allow them to support real Six Sigma projects in their roles.

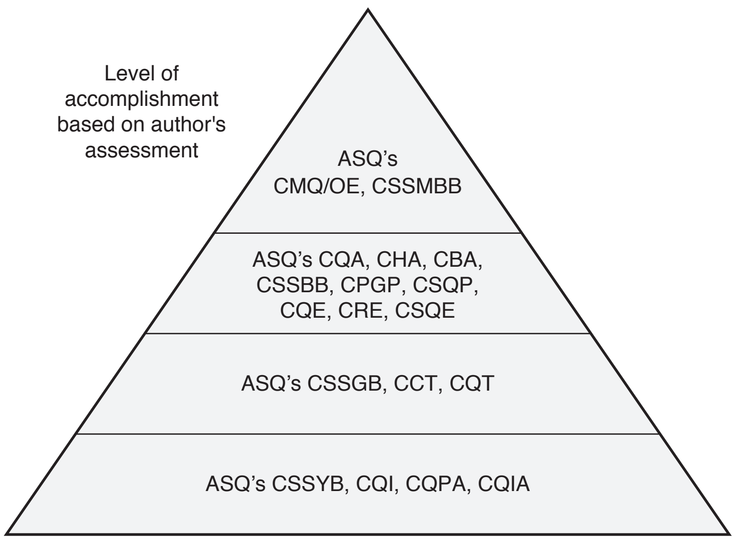
I am running an ASQ CSSYB handbook users group on LinkedIn and would greatly appreciate readers' comments and feedback on how the handbook can be improved. Constructive and respectful posts are encouraged. Users will be acknowledged if their input and feedback are found useful and incorporated into the next edition.

I encourage users of the handbook to read the ASQ *Quality Progress* publication "Test Run" to obtain tips for passing the ASQ exam (located in this book's Online Contents). Visit asq.org for more information about certification.

Test-takers may want to peruse the CSSYB keyword search located in the Online Contents. This lists the terms and phrases in the BoK and where they are located within the handbook, since in an open-book exam it is useful to the test-taker to be able to quickly find these within the book.

WHERE ARE YOU IN YOUR CAREER?

Over the course of your professional career, you have learned to use many tools. Certification as a Six Sigma Yellow Belt is the beginning of your journey of achieving higher levels of accomplishments and potentially lifelong learning. Consider this as laying the foundation. The following career pyramid provides guidance on reaching additional certifications. It is *not* a representation of ASQ certification exam requirements or prerequisites; rather, it presents a logical order of how one would progress.



Best wishes as you embark on your Six Sigma journey!

Acknowledgments

I would like to thank the numerous individuals who have taught me technical and management acumen, and hard and soft skills; have provided opportunities for me; and have been coaches and mentors to me. I would like to acknowledge Noel Wilson from the ASQ Knowledge Center for her guidance and support of my publications.

We all learn a lot from our managers. Over my 30 years in quality management I have had lots of bosses and I have learned a lot about critical thinking. My very first manager taught me attention to details. Another manager explained to me that when my requirement is one, learn to live with half. Another one famously repeated "check, recheck, and cross check." I learned to be empathetic to my colleagues and respectful to staff. While I was working at JDS Uniphase Corporation (JDSU), Peter Makin and Jordan Freed provided opportunities and support to strengthen my quality skills. Peter was so kind to offer me the opportunity to work for him and provided management visibility to my work. While I was working for Jordan, he continually encouraged me to pursue my ASQ certifications and provided necessary management support to formally launch my Six Sigma career. I am forever grateful to these individuals. Dan Courtney (formerly JDSU) provided guidance and mentoring during my early Six Sigma career. His decision to hire me in the JDSU Six Sigma organization was a great turning point for me. The hands-on experience of coaching and mentoring Black Belts and Green Belts, and setting up a global Design for Six Sigma program further strengthened my knowledge and experience. I would like to acknowledge the SunPower Corporation management team for its support of my continued professional development. I have always been fortunate to have managers who support my development.

I would like to thank Quality Press staff for their incredible patience, understanding, and support in this project, and John Noguera, CTO and cofounder of SigmaXL, Inc. I would also like to thank my coauthors from my previous publication on Six Sigma. I learned a lot working with Roderick Munro and Daniel Zrymiak on the second edition of *The* ASQ *Certified Six Sigma Green Belt Handbook*. Contents of that handbook provided a baseline for my authoring of both editions of *The* ASQ *Certified Six Sigma Yellow Belt Handbook*.

I would like to thank the following Lean Six Sigma professionals who performed careful reviews at different stages of the book: S. Anilkumar, David S. Foxx, Eric Gemunder, and Chad Walters.

Finally, there are many I am not addressing here. They all have my respect for their professionalism and continued support.

Introduction: The ASQ Certification Process

This section contains information about the exam process itself. Although not part of the exam material, this is useful information to give you background and help you understand the ASQ certification process.

THE TEST DEVELOPMENT PROCESS

Many exams, whether tests or certifications, are written by a very few people (sometimes only one person) based on what they think an examinee should know to meet the criteria of some training materials (like nearly all college exams). The American Society for Quality Control (ASQC changed its name to ASQ in 1997) started developing the Certified Quality Engineer (CQE) program in 1967, making it the oldest professional quality certification in the United States. ASQC gathered a small number of quality professionals together for the development cycle of the exam. The first CQE exam developers and a few others were grandfathered in, bypassing the taking of the first exam, which was offered in 1968.

Throughout the 1970s and early 1980s ASQC and others developed more certification exams. During this time, the issue of what the difference is between a professional certification and a state license (for example, the Professional Engineers exam process) was being raised as some U.S. states and Canada started questioning the professional community about what they were doing. ASQC and other professional organizations started trying to distinguish certifications given by their organizations from state or other governmental certifications. Basically, one is granted by peer recognition (professional organizations), the other by a governmental licensing process.

In response to this growing concern and the possibility of legal litigation as to the fairness of the exam process, ASQC wanted to become proactive about their certification process. After a benchmarking exercise and a search for what was considered the very best exam development process, ASQC partnered with the Educational Testing Service (ETS is the organization that creates and maintains the SAT exams for college-bound students).

The two organizations worked together to develop an exam development process that would be legally defensible both in court and to the various governmental organizations who might choose to challenge the process. The ASQC CQE exam was the first to be redesigned with the new development process. The basic steps include:

- Design of a survey to identify the current tools and methodologies being used in a wide breadth of industries across the United States.
- Targeting ASQ members who are currently certified in a particular discipline, as well as managers and industry leaders who are aware of the needs in the various industry sectors across the country.
- Tabulating the results of the most widely used tools, techniques, and methodologies to create a basic Body of Knowledge (BoK) for the new or redeveloped exam.
- Coordinating exam-writing workshops around the BoK, paying special attention to the demographics of the exam question writers. Each industry and all parts of the country are ensured some participation in the exam-writing process.
- During the exam-writing process the participants are broken up into teams. Each person writes a few questions based on their assigned portion of the BoK and then has two or more other team members review the questions for accuracy, references, and fairness.
- The team leader submits the questions to the exam-writing workshop lead person, who also reviews the questions. Others will then review anything that raises any issue at the workshop.
- The questions are then entered into a proposed exam bank based on their relevance to the specified exam's BoK.
- As enough questions are identified in the proposed exam bank, another workshop is called, with new reviewers to look over each question. The questions are accepted, reworked, or rejected for the BoK exam bank.
- About six months before an exam is to be given, a sort of the exam bank is conducted to select a new exam (each exam is different from all other exams) with some alternate questions for each area of the BoK. This exam mockup is then presented to an exam review workshop. These participants review every question and discuss their attributes related to the BoK. At the end of this process the exam is set for the next offering.
- Exams are prepared and distributed to testing centers or ASQ conferences where they will be administered to participants.
- All exams are graded using the identified answers from the exam bank. Once all exams are graded, a statistical cut score is developed to maintain a predetermined level of ongoing knowledge for the BoK field of experience (this is not just a simple 70% or some other numerical pass score).
- With the cut score established for a given exam sequence, all exams are then reviewed to determine those who passed. Any examinee who falls below the cut score will receive a Pareto diagram of their exam identifying where they had problems. Those who pass the exam will

receive a certification and a link to claim their digital credentials to share the accomplishment with others.

- Once an exam has been given, the exam questions are statistically reviewed for how well they discerned the knowledge of the applicants. Any questions that were generally missed or passed by a significant portion of the audience will be discarded. Only a very few of the questions will return to the exam bank for possible use on a future exam.
- Every five to seven years this cycle is repeated for each exam that ASQ offers.

This process is long and tedious, and ASQ spends a lot of time, resources, and volunteer effort to maintain this process to ensure the highest level of professionalism possible for the certifications offered by the Society. Once you pass an exam, you are encouraged to join in this process to help ensure that future exams will be meaningful to the participants.

ONGOING MAINTENANCE

As can be seen in the previous section, ASQ maintains a comprehensive process for ensuring that exams are reviewed every five years and that the exams are of the highest professionalism possible. To this end, security is tight for the entire process, and very few individuals know the entire history of an exam question's life to ensure that questions are not released to exam participants prior to an exam being given.

Some of the general activities that ASQ uses to maintain exam processes are:

- If you are a local section volunteer helping to administer a refresher program or teach a refresher course or other training process, you are not allowed to proctor an exam for the same BoK.
- If you proctor an exam for a section or conference, you are not allowed to teach that BoK.
- If you volunteer to assist with any of the activities listed in the previous section on the exam development cycle, you are not allowed to teach or publish anything related to that BoK.
- ASQ maintains an ASQ National Certification Committee for each exam that is offered through the Society. Each exam is either coordinated through an ASQ division (based on their field of expertise) and/or the ASQ National Headquarters, who coordinates with all ASQ divisions that might have a stake in a specific exam.
- These ASQ National Certification Committees are made up of ASQ member volunteers who meet on a regular basis to ensure that the processes listed above, the ASQ national activities, and other issues related to their specific exam are maintained at the highest possible level of professionalism. This includes recertification activities for those exams that have that requirement.

- These ASQ National Certification Committees ensure that the process listed in the previous section is followed (usually by participating in and/or coordinating the various events) as well as ensure that the BoK is positioned for reevaluation every five years.

After the questions have been used for a certain period of time, they will be put into an archival file with notes on each as to when it was used and statistical results of how the question performed on the exam. These old files can occasionally be used as a basis for writing new or variations of questions. Thus, it would be unlikely to see one of these questions show up on a future exam. While using practice exams (like those accompanying this handbook) for study can be useful, the user should realize that these are not the same questions that will be on the ASQ exam.

THE EXAMINATION PROCESS

Given the aforementioned process, the ASQ exam candidate should realize that anyone saying that they have inside information as to what will be on any given exam is either violating the ASQ Code of Ethics (by stealing information, in which case ASQ will prosecute if found out) or stretching the truth in the way that they are presenting the information. The ASQ certification exam process is always evolving and will rarely ever have a question in the same format on any two given exams. The candidate must be prepared to answer questions that could be reasonably extracted from the ASQ Certified Six Sigma Yellow Belt BoK (see Appendix B).

Also, given the number of various industries in the marketplace today, general questions can be asked about a given topic in any number of ways. One example, FMEA (note: acronyms are very rarely used in the actual exam). If you are in the automotive industry, you might use the *AIAG Potential Failure Mode and Effects Analysis (FMEA) Reference Manual*, 4th edition or the SAE J1739:2009 standard. On the other hand, if you are in the medical devices industry, you would have to use BS EN ISO 14971:2007 *Medical devices—Application of risk management to medical devices*. Still other industries might use the book *Failure Mode Effect Analysis: FMEA from Theory to Execution,* Second Edition. Either way, any question related to FMEA might focus on what the primary function of FMEA is, which is to manage the risk of the product or service that your organization offers to a customer (either internal or external). So, you should not be shaken if a question sounds as if it comes from an industry other than the one in which you work. The point is whether you can decipher the intent of the question as it relates to the Yellow Belt BoK and answer the question using facts and reason. The sample questions in the Online Contents have been selected from sample exam questions from ASQ Certification pages for you to use for practice. An effort was made to ensure that only the sample questions relevant to the CSSYB BoK were selected.

The *ASQ Certified Six Sigma Yellow Belt Guidelines* booklet starts off the explanation of the BoK with:

> *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 Yellow Belt (CSSYB). 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.

After the BoK is listed, a description of the meanings of *remember, understand, apply, analyze, evaluate,* and *create* is given. This is important as it tells you, the examinee, what level of knowledge you will need for that category of the BoK. The ASQ booklet lists the levels of cognition as:

Based on Bloom's Taxonomy—Revised (2001)

In addition to content *specifics, the subtext for each topic in this BoK also indicates the intended* complexity level *of the test questions for that topic. These levels are based on "Levels of Cognition" and are presented below in rank order, from least complex to most complex.*

Remember (Knowledge Level)
Recall or recognize terms, definitions, facts, ideas, materials, patterns, sequences, methods, principles, and so on.

Understand (Comprehension Level)
Read and understand descriptions, communications, reports, tables, diagrams, directions, regulations, and so on.

Apply (Application Level)
Know when and how to use ideas, procedures, methods, formulas, principles, theories, and so on.

Analyze (Analysis Level)
Break down information into its constituent parts and recognize their relationship to one another and how they are organized; identify sublevel factors or salient data from a complex scenario.

Evaluate (Evaluation Level)
Make judgments about the value of proposed ideas, solutions, and so on, by comparing the proposal to specific criteria or standards.

Create (Synthesis Level)
Put parts or elements together in such a way as to reveal a pattern or structure not clearly there before; identify which data or information from a complex set are appropriate to examine further or from which supported conclusions can be drawn.

These words can be kept in mind while reviewing the chapters in this book to get a better sense of the detail of questions that could be asked in that section. This is also why it may appear that some material is covered in more than one section of the BoK.

To prepare for the actual exam, I suggest that you do the following:

- Peruse the ASQ certification website—"Taking the Exam" FAQs.
- Select the reference that you have used in preparing for the exam. You should be familiar with how the reference is laid out and how you will use it.
- Create an index of your planned references—you are allowed to use self-prepared information as long as there are no practice exam questions in the material.
- Consider having a good Standard English dictionary available. Sometimes a word might be used in the questions that you may not be familiar with.
- Arrive at the exam site early so that you can set up your materials in a manner that best fits your needs. You might even call the chief proctor ahead of time to learn the room layout if you have not been to the particular exam site before.
- Remember that anything that you write on during the exam (scratch paper, exam pages, answer sheets, and so on) must be turned in to the proctor at the end of the exam. Thus, during the exam do not write in any of your references that you want to take home with you.
- Relax and breathe.

Additional advice given in the ASQ Certified Six Sigma Yellow Belt brochure includes:

- *Read all of the questions on the first page of the test so you realize that you do know the material. In other words, relax.*
- *Read each question thoroughly. Don't assume you know what's being asked.*
- *Eliminate implausible answers and move quickly past the obviously wrong choices.*
- *Keep in mind that an answer may be a correct statement in itself but may not answer the question.*
- *Two answers may say exactly the opposite things or may be very similar. Read them again to decide what makes one correct and the other wrong.*
- *ASQ does not subtract points for incorrect answers. Answer every question. There is no penalty for guessing, so you have a minimum 25% chance of getting it right, and even higher if you are successful in eliminating one or two of the answers as incorrect.*
- *Go through and answer the questions you know. Then go through and read the ones you're unsure of.*

- *Mark those you are still uncomfortable with. You will narrow the field down to just a few questions you will need to spend more time on. These are the questions you might want to use your reference books for.*
- *Be aware of the time available for the exam and the remaining time as you work through the exam.*
- *Do not select more than one answer for a question. If you do, it will be scored as a "blank." For example, you think that both A and C are correct answers. Select only one answer and use the comment sheet supplied with your test to point out why you think both A and C are correct. Your comments will be reviewed before results are reported.*

Taking an exam (offered by ASQ or any other organization) is a matter of preparation on the participant's part, and your results will show how well you achieved the exam requirements. I have seen people who, based on overall education, *should* pass an exam but do not do well. On the other hand, a person who I thought might struggle but studied very hard actually passed the exam. Study and use your reference materials, and know where and how to find information when you need it. Few people can memorize everything, so the next best thing is knowing how to find information quickly when needed so that you can finish the exam in a timely manner.

The breadth and scope of material within this handbook are based on the current version of the ASQ BoK for Certified Six Sigma Yellow Belt practitioners. When reviewing the material, there are two considerations: coverage and intensity.

Coverage reflects the material in relation to the expected scope of the exam. ASQ has defined for each BoK category the number of questions expected to be present on the exam. It is important to devote the appropriate time to each section in order to ensure proper preparation. Without considering the coverage of the BoK, there is a risk that certain portions will be inadequately addressed in advance of the exam. One practice is to create a matrix on a spreadsheet indicating the BoK items on one axis and the study progress made for each item on the other. Maintaining such a matrix would clearly indicate those areas where mastery has been achieved and where more effort is required.

Intensity refers to the learning level specified by ASQ, as referenced by the Bloom's Taxonomy category.

Those topic areas with the highest knowledge levels require additional effort by the examinee to fully master the concepts to sufficiently select or derive the correct response on the exam. Consequently, more effort should be devoted to those BoK items with the highest levels of knowledge, as these will align with the most complicated and time-consuming questions on the exam. For convenience, those items with the highest levels have been included within the following table for extra attention.

The components of the BoK are explained below with two examples. In the Yellow Belt BoK, only two levels of cognition are used: "Understand" and "Apply."

Section	Subsection	Knowledge area	Knowledge item
I. Six Sigma Fundamentals	D. Team basics	1. Types of teams	Identify the various types of teams that operate within an organization (i.e., continuous improvement, self-managed, and cross-functional) and their value. (Understand)
II. Define Phase	A. Project identification	4. Process inputs and outputs	Use SIPOC (suppliers, inputs, process, outputs, customers) to identify and define important elements of a process. (Apply)

Part I

Six Sigma Fundamentals

Chapter 1

Six Sigma Foundations and Principles

> Describe the purpose of six sigma (reducing variation), its methodology (DMAIC) and its evolution from quality. Describe the value of six sigma to the organization as a whole. (Understand)
>
> **Body of Knowledge I.A**

PURPOSE OF SIX SIGMA: REDUCING VARIATION

The main purpose of a for-profit organization is to generate money for operating the business and making profits for shareholders. Even the organization that is not for profit (e.g., American Society for Quality [ASQ]) has to generate enough money to cover operational costs and to fund future programs that bring value to customers (i.e., ASQ members). These organizations generate income by offering products and services to customers. There is no guarantee that every product and service delivered to customers will be identical. There is some variability that is inherent to products and services. What if the variability increases to an extent that it affects the customer? Let's look at some different scenarios. If you purchase a gallon of gas and the gas pump dispenses anywhere from three-fourths of a gallon to one gallon, would you find that acceptable? If a healthcare clinic delivers between 0.25 mL and 1 mL of the flu vaccine against the specification of 0.5 mL ± 0.05 mL, would you still get a flu shot from this clinic? While variability is inherent, organizations strive to keep it as low as possible in order to deliver products and services that meet or exceed customer expectations.

Highly variable products and services result in poor quality, and the organization must spend money to correct the defect. If an organization spends more than it takes in, it will be out of business. Thus, the challenge for every organization is to become profitable at whatever it does so that it can continue to do what it does. Managers, employees, suppliers, and customers all have their wants and needs that the business must satisfy in an effective and efficient manner so profit can be achieved. Six Sigma as a disciplined methodology for improvement and problem solving helps achieve just that with a focus on the bottom line.

Six Sigma is a structured and disciplined process designed to consistently deliver perfect products and services. It aims to improve the bottom line by finding and eliminating the causes of mistakes and defects in business processes. *Sigma* (σ) is a statistical term that refers to the standard deviation of a process about its mean.

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. Common threads of these definitions are the following:

- Use of teams that are assigned to well-defined projects that have direct impact on the organization's bottom line.
- Training in statistical thinking at all levels of the organization and providing key people with extensive training in advanced statistics and project management. These key people are designated Black Belts and Master 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.

Opinions on the definition of Six Sigma differ:

- *Philosophy.* The philosophical perspective views all work as processes that can be defined, measured, analyzed, improved, and controlled. Processes require inputs and produce outputs. If you can control the inputs, you can 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. These tools include statistical process 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, as it continues to evolve.
- *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 structured approach.
- *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 advocated by Motorola).

At this point, Six Sigma purists are 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 is blurred. With greater frequency, we are hearing the term "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—originally known as lean manufacturing and now broadly accepted as lean enterprise—drives out waste (non-value-added activities) through value stream mapping and promotes work standardization. Six Sigma practitioners should be well versed in both lean and Six Sigma methodologies. Most practitioners advocate to implement lean first to remove wastes and standardize processes, and then implement Six Sigma to reduce variability and make the process efficient. **Effectiveness before efficiency**.

METHODOLOGY (DMAIC)

The DMAIC model is very similar to the PDCA (Plan-Do-Check-Act) or PDSA (Plan-Do-Study-Act) model that you may already be using. Table 1.1 shows the alignment between these models.

A key factor is for management to provide the time and resources needed to accomplish each phase in striving for continual improvement. This is one of the driving forces that make Six Sigma different from other quality improvement programs. Other driving forces include getting everyone in the organization involved, getting the resources to supply data to everyone more quickly, and getting financial data (e.g., cost of quality [COQ] analysis).

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

Define: Identify an issue causing decreased customer satisfaction, a reduced bottom line, safety incidents, supplier quality failure, and so forth

Measure: Collect data from the process and verify the validity of the data

Analyze: Study the process data to identify root cause(s)

Improve: Act on the root causes to change the process for the better

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. The list shown in Table 1.2 is only a quick overview of many of these items. More detailed information can be found in the references that focus solely on quality tools. (Please refer to the bibliography of this book.)

Table 1.1 Mapping of PDCA with Six Sigma DMAIC model.

Plan	Define
Plan	Measure
Plan	Analyze
Do/Check	Improve
Act	Control

Table 1.2 Six Sigma tools overview by stage.

Tool	Description
Define	
SIPOC (supplier-input-process-output-customer)	Tool to describe and understand a process more clearly. Supplier can also be interpreted as "source of inputs" or "who supplies the inputs," and customer can be interpreted as the "recipient of the outputs."
Is-is not analysis	Tool helpful in defining a problem. Oftentimes, understanding what is not a problem will help the team zero in on areas that are a problem. This saves a significant amount of time during problem solving.
Timeline of events	Tool used to understand the problem through a sequence of events (one event leads to another).
Trend chart	Tool used to understand process trends (favorable and unfavorable) from historical events of data.
Run chart	Tool used to understand process patterns from historical data.
Process flowchart	Graphical representation of the sequence of interrelated activities.
Current state map	A value stream map that represents the current state of a process.
GANTT chart	Management of schedule, resources, cost, and risk used in project management.
Stakeholder analysis	Tool used to understand the people who are influential to a project and those who offer resistance coupled with their level of involvement in a project.
Measure	
Data collection plan	Plan describing what, why, where, when, who, and how of data collection (5W1H). Prior to collecting data, having a detailed collection plan can help make collection more effective.
Measurement systems analysis (MSA)	Analysis of the capability of a measurement system (tools, methods, people, environment, etc.).
Benchmark	Start by setting the current baseline for the process.
Process capability	Ability of the process to meet expected output. Often represented by indices Cp and Cpk (the higher the indices, the better).
Analyze	
Why-why	Method of continuing to ask "why" on a problem symptom until the root cause is reached.
Hypothesis tests	Statistical methods to test hypothesis on process improvement.
Statistical sampling	Statistically valid sampling (e.g., power and sample size, acceptance sampling).
Improve	
Design of experiments	Tool for understanding cause and effect in a process and for optimizing process variables to achieve improved performance.
Future value stream map	Creates a "should be" future state value stream with non-value-added process steps removed.

Continued

Table 1.2 *Continued.*

Tool	Description
Theory of constraints	Tool for understanding bottlenecks.
FMEA	Tool to evaluate potential risk and prioritize actions.
Poka-yoke (mistake proofing)	Concept that prevents errors from happening in processes and products by "designing in" controls.
Control	
Process behavior chart	Tool to help understand the behavior of a process by analyzing historical patterns and trends.
Control plan	Document that provides basic information on what is required to manage a process during the manufacturing or service delivery.
Process audit	Tool to verify compliance of a process as per the specification.
Cost of quality	A measure that captures the cost of conformance and the cost of nonconformance; often represented as a ratio comparing to the revenue or cost of goods sold of an organization.
Tools applicable to all stages	
Brainstorming	Tool (and a process) for collecting inputs and ideas from team members without making any instant judgments.
Seven quality tools	Check sheet, histogram, flowchart, cause and effect diagram, Pareto chart, run chart, scatter diagram (see Chapter 5 for a description and application of these tools).

Note: Some tools are applicable in more than one stage of DMAIC (see Table 5.1 in Chapter 5).

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. In the past, when an employee tried to tell a supervisor that something was wrong with a machine or process, the employee had no means to prove his or her claim. Now we have the means to not only tell what needs to be done but also demonstrate it. Following this process creates a road map for continual improvement and, once started, is a never-ending journey. These tools and methods have proven themselves useful just about everywhere: shop floors, front offices, schools, hospitals, churches, and even at home.

EVOLUTION OF SIX SIGMA FROM QUALITY

Organizations are always looking for ways to keep their customers satisfied and loyal. Many different techniques have been employed over the years to keep customers coming back. Unfortunately for many organizations, people's wants and needs change over time, leaving the organization with the challenge of finding new and better ways of satisfying those needs and wants. Organizations need to keep up with the customer's changing needs and expectations. Two organizations come to mind. A very successful market leader in photographic film development technology lost significant market share after the introduction of the digital camera. A successful cellphone company was reduced to a small-time player after the competition introduced innovative smartphones.

Concepts of quality and waste reduction have been in the minds of people for centuries.[1] The idea of setting standards of work goes back more than a century and was the foundation of the guilds and crafts trades that developed over the years. From the mid-1800s to the early 1900s, separation of work was developed to speed up the production process. Innovators like Frederick Taylor and Henry Ford developed ideas and techniques that are still with us today.

Given these new methods of doing business, the quality control/quality assurance (QC/QA) specialist was created to ensure that standards were established and maintained and that customers were satisfied. In many organizations, however, this also created a separation of tasks, and many people in organizations came to think of the responsibility of satisfying customers as in the hands of those in the QC/QA departments instead of in the hands of the people who actually made the product or provided the service. This was especially true in the United States during the 1950s, 1960s, and 1970s as managers looked for better ways to manage all the resources of the organization. Even today, many organizations still struggle with meeting customer satisfaction.

In the mid-1920s a young engineer named Walter A. Shewhart devised a technique of using graphs to monitor a process to determine whether the process was acting in a predictable manner or whether what he termed "special causes" were affecting the process. These charts became known as quality control charts; today we sometimes call them statistical process control charts or 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; these are summarized in Table 1.3.

Table 1.3 Approaches to quality over the years.

Quality approach	Approximate time frame	Short description
Company-wide quality control (CWQC)	1960–1980	Introduced by Ishikawa from Japan. Quality is applicable to the entire organization, not just to products.
Quality circles	1979–1981	Quality improvement or self-sustaining improvement study groups composed of a small number of employees (10 or fewer mostly from the shop floor) and their supervisor. Quality circles originated in Japan, where they are called "quality control circles."
Total quality management (TQM)	1980–present	Management approach to long-term success through customer satisfaction.
Statistical process control (SPC)	Mid-1980s	The application of statistical techniques to control a process. Also called "statistical quality control."

Continued

Table 1.3 *Continued.*

Quality approach	Approximate time frame	Short description
ISO 9000 series of quality management systems	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 162 member countries. The standards underwent revisions and amendment in 1994, 2000, 2008, and 2015. Related standards include ISO 9000:2015 (definitions), ISO 9001:2015 (requirements), and ISO 9004:2009 (Managing for sustained success).
Baldrige Award criteria	1987–present	An award established by the US Congress in 1987 to raise awareness of quality management and recognize US companies that have implemented successful quality management systems. Awards are given annually in each of the following categories: business, education, healthcare, and nonprofit. The award is named after the late secretary of commerce Malcolm Baldrige, a proponent of quality management. The US Commerce Department's National Institute of Standards and Technology manages the award, and ASQ administers it.
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 categories that can be benchmarked include strategies, project, process, products, etc.
Balanced scorecard	1990s–present	A management concept that helps managers at all levels monitor their results in key areas.
Six Sigma	1995–present	A structured approach to improvement and problem solving that provides heavy emphasis on business bottom line and sustainability.
Business process reengineering	1996–1997	A breakthrough approach involving the restructuring of an entire organization and its processes.
Lean manufacturing	2000–present	Inspired by Toyota Production System, companies worldwide started to pay attention to process fundamentals of reducing waste, standardization, employee empowerment, etc. This approach works in tandem with Six Sigma.

VALUE OF SIX SIGMA TO THE ORGANIZATION AS A WHOLE

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, followed by the use of process behavioral studies to maintain the gains.[2] Six Sigma has been described as a breakthrough system[3] and is used in many organizations today in a variety of applications. Basically, Six Sigma is about collecting data on a process and using that data to analyze and interpret what is happening in the process so that it can be improved to satisfy the customer's requirements.[4] A basic process can be defined as an input, transformation, and output.

Six Sigma was first started at Motorola and was then further developed at General Electric into more of what we know today. Among practitioners, Six Sigma is referred to as "TQM on steroids." By following a prescribed process, the entire organization starts to look at everything 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 end customer, who uses the products or services that our organization produces (external customer). To assist in this process, the supplier and the customer are added to the basic process definition listed earlier, creating the SIPOC identification: *supplier, input, process, output, customer*. This is used especially to help define the boundaries of what is to be studied. (Some organizations prefer COPIS over SIPOC. Their rationale is that requirements start with putting the customer first.)

For some, the idea of improving a process is a waste of time that should not be bothered with ("We are already working as hard as we can"). But as Joseph 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 people have not necessarily kept pace, and we wake up to the existence of a wide gap."[5] This is one explanation for why accidents and product rejections happen in our shops. If the root cause is found for any accident or rejection of product or service, it can usually be traced back to many small changes that occurred either within our own organization or at our supplier. We may or may not see these changes. Mostly we tend to ignore them as trivial.

By using Six Sigma methodologies, we will be able to find those bits of changes and determine which ones require process improvement and which ones need to be corrected and controlled. This process is not a magic bullet approach, nor is it meant to be a quick fix. Logical use of the tools over time will save us resources and effort in doing our daily jobs.

A Six Sigma Yellow Belt's Role

As a Six Sigma Yellow Belt, you are new to the world of Six Sigma. You may play a relatively small yet important role in the Six Sigma implementation. You may be interested in strengthening your foundational knowledge. Six Sigma Yellow Belts can be entry-level employees seeking to improve their knowledge or management executives who require an overview of Six Sigma and DMAIC in order to offer support as sponsors or champions. Note that the role of Six Sigma Yellow Belt may vary between organizations.

You may already be familiar with several of the tools and methods used in this problem-solving process, and a few may be new to you. You may very well ask, "How is this any different from what we have been doing?" This will need to be answered 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 top management will be more involved with your problem-solving efforts and in the everyday problems found in your work areas. This involvement may be either sponsorship or even participation where appropriate.

You may already have control plans, process sheets, standard operating procedures, or any number of other tools that you use in your daily work. The Six Sigma model for improvement should not replace anything that you are currently doing, but it should be used to review daily work and to look for areas where the process can be improved in light of what your customers want and need. Just because you are doing the same things that you have always done, is that what your customers want?

We are entering a journey of continual improvement that involves not only our work but our lives. Some of us have been on this journey for some time, while others may be just starting. Through the Six Sigma methodology and by 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 Six Sigma or some other method (e.g., quality operating system [QOS], continuous improvement [CI], TQM, or "your company name" production system). As a process operator, you will be asked by your supervisor or management to help implement improvement of the process or processes you work with. Your challenge will be to look at the process for simple improvements that can be made (preventive maintenance, cleanliness, replacement of worn-out parts, and so on), as well as assist in measuring certain factors of the process in order to find better ways of performing the process.

You may be expected to use the tools in this book, and possibly tools in other books, to study your work and processes for improvement ideas and to implement those ideas. You may already be familiar with some of these tools, and the challenge will be how to use them, possibly in new ways, to make changes that will help your company stay in business in today's fiercely competitive world. We no longer compete against others within just our own country, but against others from countries around the world. How can we compete with our competitors in other countries that can manufacture product or provide service faster, better, and at a lower cost than we can? This is the question that should be on your team's mind.

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, 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) and 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. Some operators initially view this effort as only more work, but find that doing these studies actually saves them a lot of time and grief in the future as things start to improve and machines start to work better. Questions to ask yourself now are, How often does your process slow down or stop due to something not working the way it should? and Is the output ever scrapped by someone down the line (including at your external customers) because something was missed or processed incorrectly 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. This will allow you to modify it as appropriate and give the customer the best possible output.

The Six Sigma Road Map

As we prepare for the Six Sigma journey, here is a quick view of the suggested map we should 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 for continual improvement.

QUESTIONS

1. Structured problem solving and continual improvement approaches like PDCA have been around since the 1950s. The 1980s and 1990s saw the introduction of many new approaches and methodologies like TQM and business process reengineering. How did an improvement methodology like Six Sigma become the mantra of management and the most widely accepted methodology by organizations?
2. Research the common criticisms of Six Sigma and prepare your position. You may support the criticisms or counterargue with your viewpoint. Ask your audience to weigh in.

Chapter 2

Lean Foundations and Principles

Describe the purpose of lean (waste elimination) and its methodologies (just-in-time, poka-yoke, kanban, value-stream mapping). Describe the value of lean to the organization as a whole. (Understand)

Body of Knowledge I.B

PURPOSE OF LEAN

The purpose of lean is to reduce waste in the value stream and provide maximum value to our customers; that is, do more with less. Over the years we have adopted many industry practices that emphasize maximizing output from our investment (like machinery) or from the people we employ. We have not considered whether such outputs are required by our customers at the level of quality and in the quantity they want. We have produced goods that piled up in inventories. Production managers were rewarded for overproduction. Sales managers were pressured to sell the inventories. Gullible customers fell for the marketing ploy and purchased the product only to realize that it was not what they wanted. We ended up with a society that oversupplied products that were undervalued by consumers. There were no winners. Lean concepts address all these weaknesses in the traditional business model and industry practices and provide methodologies that will bring the utmost value to our customers and ensure the organization is economically sustainable.

Value Stream

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

There are three main components of a value stream:

1. **The flow of materials** from receipt of supplier material to delivery of finished goods and services to customers. Examples:
   - — Raw material shipped weekly (or at periodic intervals) 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 materials and transformation of goods and services. Example:
   - — Purchase order to supplier, internal work order, shipping notice

This concept is visually illustrated with 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-progress, operators, and so on. Value stream mapping is a simple yet powerful tool. The analysis subsequent to value stream mapping—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 its customers is a *lean enterprise* organization.

Becoming a lean enterprise requires a change in people's 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. Walk the process. Go to the gemba (workplace) and produce a value stream map. This is also referred to as a value chain diagram. It has boxes labeled with each step in the process. Information about timing and inventory is provided next to each process box. Figure 2.1 shows some of the symbols used in value stream maps. Figure 2.2 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, etc.).

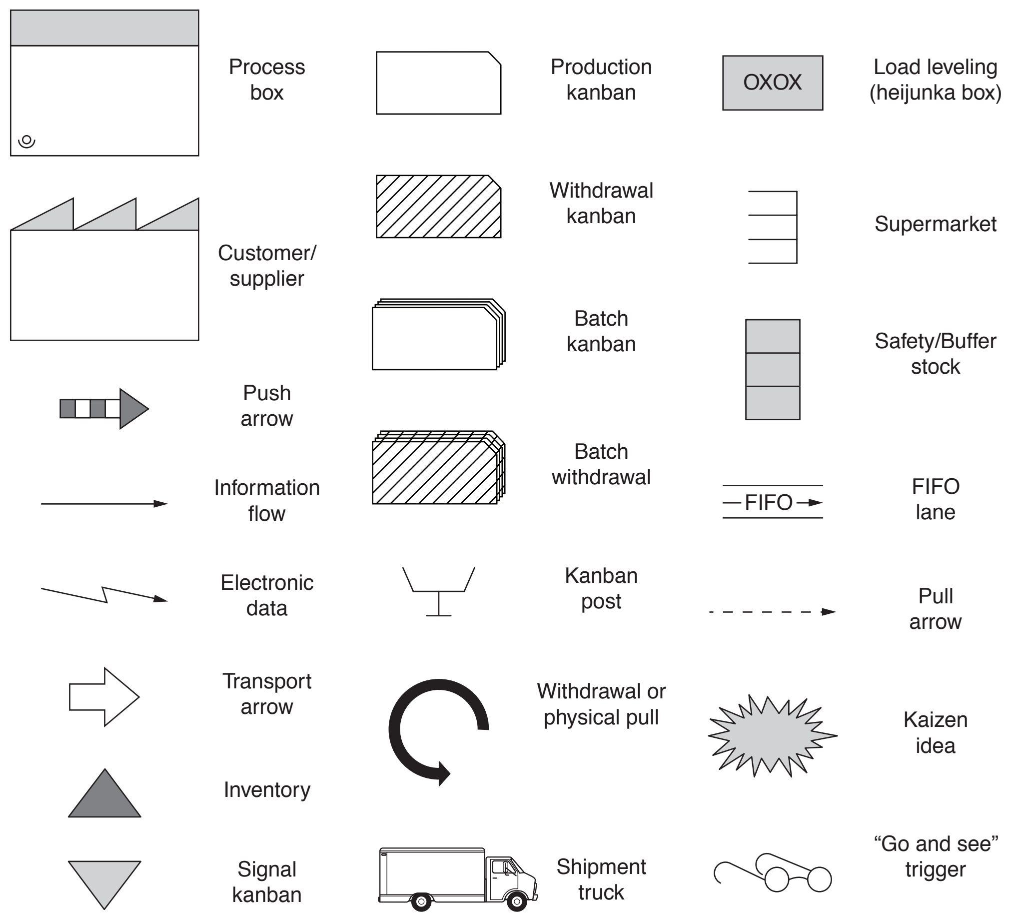


Figure 2.1 Common symbols used in value stream mapping.

— Design changes may be delayed as they work their way through the inventory.

— Money sitting in inventory could be used more productively elsewhere (locked cash).

— 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.

3. Analyze the entire value stream for wasteful steps. These steps are called non-value-added activities and are discussed in detail later in this chapter.

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. In a process where pull-based flow has reached

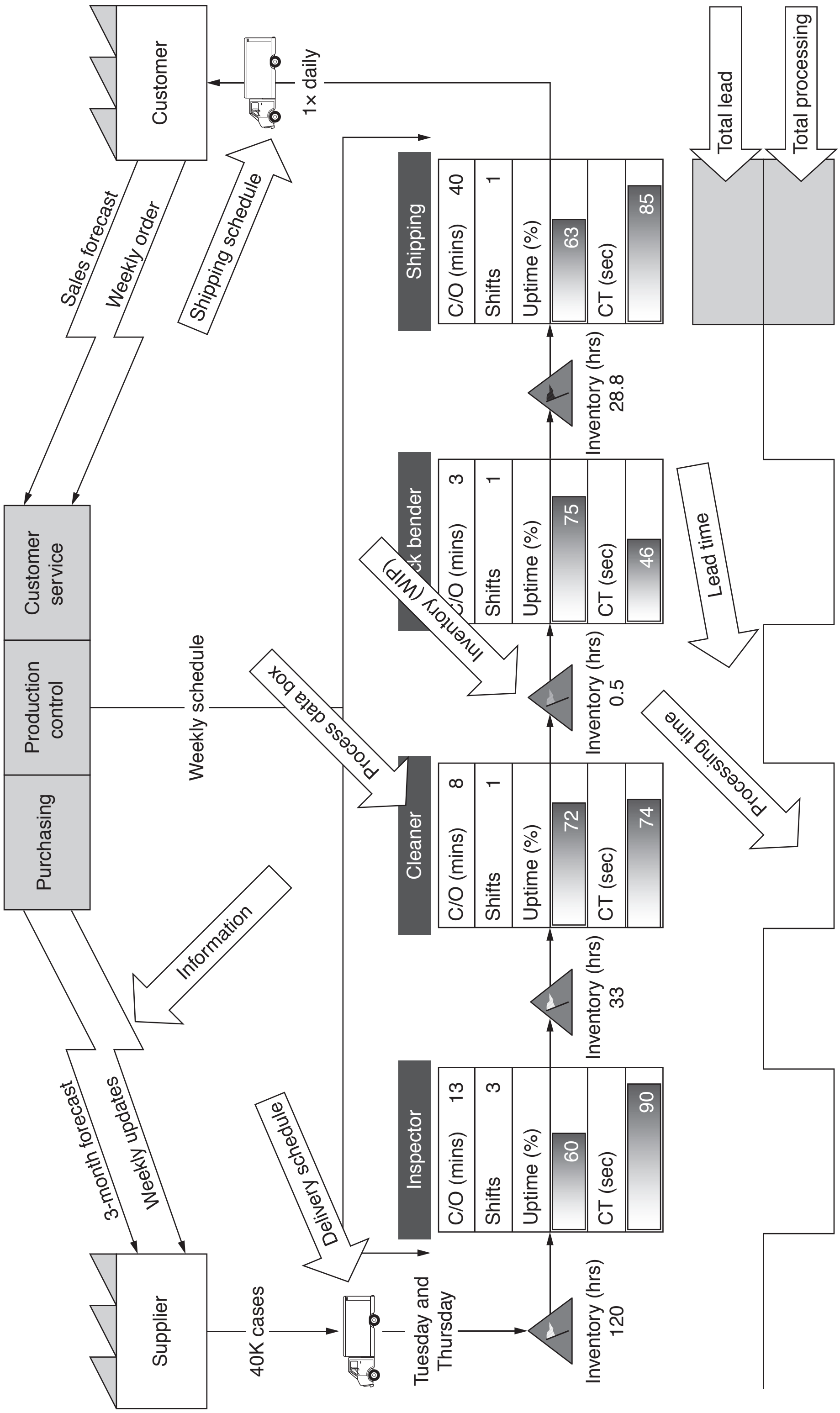


Figure 2.2 Value stream map example.

perfection, a customer order for an item will trigger the production of all the component parts for that item.

5. Extend the value stream map upstream into suppliers' plants. When beginning the process, identify a manageable scope with boundaries. The flows of information, material, knowledge, and money are all potential targets for lean improvements.

LEAN METHODOLOGIES

5S

5S is a workplace organization method that can help improve the efficiency and management of operations (see Figure 2.3). 5S is the simplest and most practical improvement that an individual or organization can start with. It requires few or no resources, yet the payback can be impressive from the day of implementation. A process is impacted by its environment, as is the ability of personnel to visually recognize and respond to process changes. Improvements in the general state of the work area, including access to hand tools, 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.

A workbench cluttered with tools and accessories wastes the valuable time of skilled workers and causes distraction from work, resulting in poor quality and safety incidents. 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 on the path to becoming a lean enterprise organization.

5S and other Toyota Production System methodologies that have helped organizations reduce waste and create value are not limited to manufacturing. The healthcare industry has also taken notice of the lean methodologies and has begun to apply them to improve stakeholder value.[1]

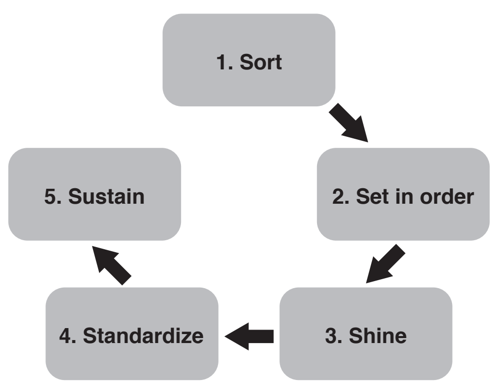


Figure 2.3 The 5S cycle.

The sequence for 5S is as follows:

Sort. Remove unneeded items. Be it 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 more difficult to search for needed items, sometimes even causing safety issues. The first step is to sort through the items as required and clean 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. 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**. Rarely required items, like machine manuals, shop floor layout plans, and so on, can be kept in an out-of-the-way area.

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. For example, cleaning the inspection surface plate provides better measurement results, cleaning the equipment work table provides for better movement, and cleaning the floor helps prevent accidents from oil spills. For some industries, such as semiconductor manufacturing, cleanliness is mandatory and is measured in particle count. Excessive particles in the air beyond the allowable limit could result in poor process yield or, even worse, reliability failure in the field.

Standardize. This involves developing checklists (including a checklist for 5S itself—see Figure 2.4), standards, and work instructions to keep the work area clean and orderly. Standardization involves tools, processes, people skills, materials, and operating environment. Standardization helps reduce variability.

Sustain. This is the most difficult step in 5S. Most organizations are initially successful with the first four steps, but sustaining the efforts requires support from management and empowerment of employees. Management needs to realize that this is time well spent and should be willing to invest 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. Empowered employees take pride in their work.

The 5S methodology can be further improved to include employee and customer safety (Figure 2.5).

Visual Factory

A visual factory provides visual identification of the status of material and information throughout the value stream. Examples of a visual factory include providing the status of material in/out at a raw material warehouse; showing units produced, units needed to complete order, and total produced by shift or day on a

Category	Item	Rating level					Remarks
		L0	L1	L2	L3	L4	
Sort (Organization)	Distinguish between what is needed and not needed						
	Unneeded equipment, tools, furniture, and so on, are present						
	Unneeded items are on walls, bulletin boards, and so on						
	Items are present in aisles, stairways, corners, and so on						
	Unneeded inventory, supplies, arts, or materials are present						
	Safety hazards (water, oil, chemical, machines) exist						
Set in Order (Orderliness)	A place for everything and everything in its place						
	Correct places for items are not obvious						
	Items are not in their places						
	Aisles, workstations, equipment locations are not indicated						
	Items are not put away immediately after use						
	Height and quantity limits are not obvious						
Shine (Cleanliness)	Cleaning and looking for ways to keep it clean and organized						
	Floors, walls, stairs, and surfaces are not free of dirt, oil, and grease						
	Equipment is not kept clean and free of dirt, oil, and grease						
	Cleaning materials are not easily accessible						
	Lines, labels, signs, and so on are not clean and unbroken						
	Other cleaning problems of any kind are present						
Standardize (Adherence)	Maintain and monitor the first three categories						
	Necessary information is not visible						
	All standards are not known and visible						
	Checklists don't exist for cleaning and maintenance jobs						
	All quanitities and limits are not easily recognizable						
	How many items can't be located in 30 seconds?						
Sustain (Self-discipline)	Stick to the rules						
	How many workers have not had 5S training?						
	How many times last week was daily 5S not performed?						
	Number of times that personal belongings are not neatly stored						
	Number of times job aids are not available or up to date						
	Number of times last week daily 5S inspections not performed						
	TOTAL						

Number of problems	3 or more	3–4	2	1	None
Rating level	Level 0 (L0)	Level 1 (L1)	Level 2 (L2)	Level 3 (L3)	Level 4 (L4)

Figure 2.4 5S workplace scan diagnostic checklist.

Source: Jack B. ReVelle, *Quality Essentials: A Reference Guide from A to Z* (Milwaukee, WI: ASQ Quality Press, 2004), 56–58, quoted in ASQ, "Five S (5S) Tutorial.

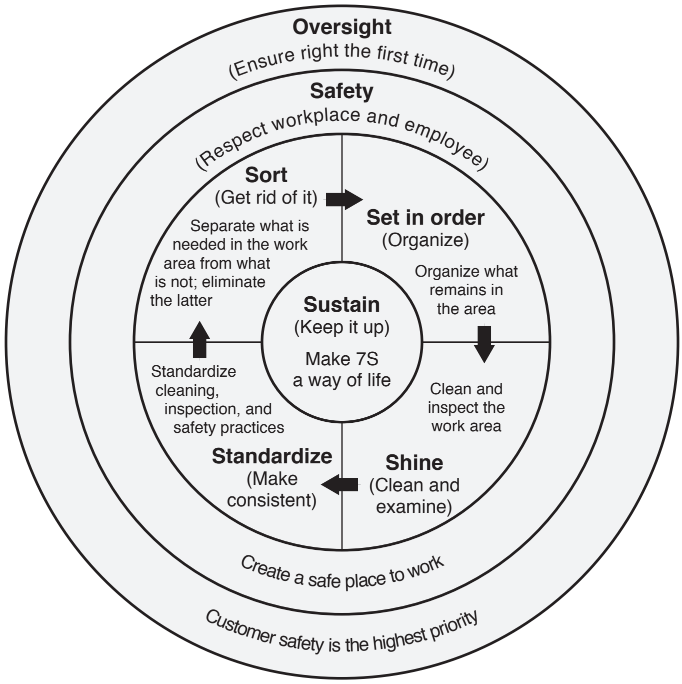


Figure 2.5 The 7S adaptation (Hirano).

Source: H. Hirano, *5 Pillars of the Visual Workplace: The Sourcebook for 5S Implementation* (Portland, OR: Productivity, Inc., 1995).

production display board; and indicating status with red, yellow, and green lights on the machine (Figure 2.6). 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. This may take anywhere from several minutes to several hours.

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

Part #	A1308
Model #	1705
Planned for the week	5000
Complete	3800
Balance to reach goal	1200

Figure 2.6 Visual factory.

Kaizen versus Kaizen Event (Kaikaku)

Kaizen is a Japanese term meaning "change for improvement," or improving processes through small, incremental steps. Breakthrough improvement is referred to by another Japanese term, kaikaku.

Kaikaku is referred to in North America as a kaizen event or kaizen blitz. Hence, many practitioners are often confused by 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 to take 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.

Pull System

The pull system is a vital component of the just-in-time (JIT) concept and lean implementation. Traditionally, organizations have produced more than the customer wants and have stored the excess as inventory or work in progress; finished goods tended to be pushed to the next process. This was done with the idea of optimizing the subprocess and not looking at the value stream as a whole. In a pull system, the process produces only when there is a pull from the subsequent process. This is signaled as either an empty bin or a kanban card. The pull system links accurate information with the process to minimize waiting and overproduction.

Just-in-Time

JIT is an inventory strategy that provides for the delivery of material or product at the exact time and place where it will be used. When this material requirements planning system is implemented, there is a reduction of in-process inventory and its related costs (such as inventory carrying cost and warehouse space rental cost), which in turn can dramatically increase the return on investment, quality, and efficiency of an organization.

By implementing JIT, buffer stock is eliminated or reduced, and new stock is ordered when stock reaches the reorder level (facilitated by the use of kanban cards/signals).

Kanban

A system is best controlled when material and information flow 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 and associated costs may occur and customers may be disappointed. A properly administered kanban system will improve system control by ensuring 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 (can be either a physical card or digital information) is the signal for production to pull material from the previous step. Kanban works with the pull system to deliver customer demand. The kanban quantity is mathematically calculated and fine-tuned during practical implementation. It usually takes a while for the organization to perfect the kanban. Kanban is a more mature concept than the other lean methodologies. It is important that other fundamentals of lean (5S, standard work, total productive maintenance [TPM], and variation reduction) be 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.

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 daily life that use the mistake-proofing concept, such as electrical outlets that prevent plugging an electrical cord in the wrong way (Figure 2.7), valves that shut once the maximum pressure is reached, and fixtures that prevent loading the component in a wrong orientation. A window envelope is also a mistake-proofing method that allows users to see that the letter has the right address. Similarly, detection-type mistake proofing alerts a user immediately after an error is made (to prevent further errors), for example, an alert that sounds if the driver forgets to turn off a car's headlights, and an automatic gauging machine that sounds an alarm when an oversized or undersized part is produced.

Standard Work

Standard work is a tool that defines the interaction between personnel 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.

Figure 2.7 Examples of mistake proofing.

The basic idea is to make manufacturing methods and/or service processes consistent. Quality management systems like ISO 9001 provide a basic foundation for 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. Standard work aligns with the 5S step "standardize."

VALUE OF LEAN TO THE ORGANIZATION

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.

Once the concept of value is understood, the target cost for the product or service can be determined. According to Womack, Jones, and Roos, the target cost is a mixture of current selling prices of competitors and examination of elimination of waste by lean methods.[2]

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 perform functions that 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. For example, the customer expects to pay for the printing of a document, but does not want to pay for corrections caused by errors of the supplier. A key step in making an organization 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 perspective. This helps address the response "This is the way we've always done it."

There are, of course, gray areas where the line between value-added and non-value-added is not 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 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, an electrical product manufacturer must conduct a safety test for every product in order to comply with regulatory requirements. Customers are willing to pay for the product safety certifications, so this test step is a value-added activity.

Case studies from ASQ and from the organizations that I have been involved with in value stream mapping have shown that an overwhelming proportion of lead time is non-value-added, much of it spent waiting for the next step. Yet efforts to decrease lead time over the years have often focused on accelerating value-added functions rather than reducing or eliminating non-value-added functions.

Waste (Muda)

Categories of waste, or *muda* as it is referred to in some sources, include overproduction, excess motion, waiting, inventory, excess movement of material, defect correction (rework), excess processing, and lost creativity (underutilization of resource skills).

Overproduction

Overproduction is defined as making more than is needed or making it earlier or faster than is needed by the next process; its principal symptom is excess work-in-progress (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. In some organizations, overproduction is attributed to utilization of labor. All WIP should be continuously scrutinized for possible reduction or elimination.

Excess Motion

Excess motion is caused by poor workplace layout, including awkward positioning of supplies and equipment. This results in ergonomic problems, safety incidents, time wasted searching for supplies or equipment, and 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 employees from the impacted process. In addition, it is essential to include people with the authority to make decisions.

Waiting

Waiting is typically caused by such events as delayed shipments, long setup times, or an insufficient amount of people to provide service. It results in a 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. Carefully planned and executed scheduling is key to addressing this waste.

Inventory

When inventories of raw materials, finished goods, or WIP are maintained, costs are incurred for environmental control, record keeping, storage and retrieval, and so on. These functions add no value for the customer. Of course, some inventory may be necessary, but if an organization finds a way to reduce costs by reducing inventory, it may be able to reduce overall cost. 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 2.8, illustrates how excess inventory prevents the solution of 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

Large conveyor systems, huge fleets of forklifts, and so on, make production costly and complex, and often reduce quality through handling and storing. Poor plant layout is usually to blame. Plants with function-oriented departments (all drilling machines together, all polishing machines together, and so on) require excessive material movement. A better plan is to gather equipment together that

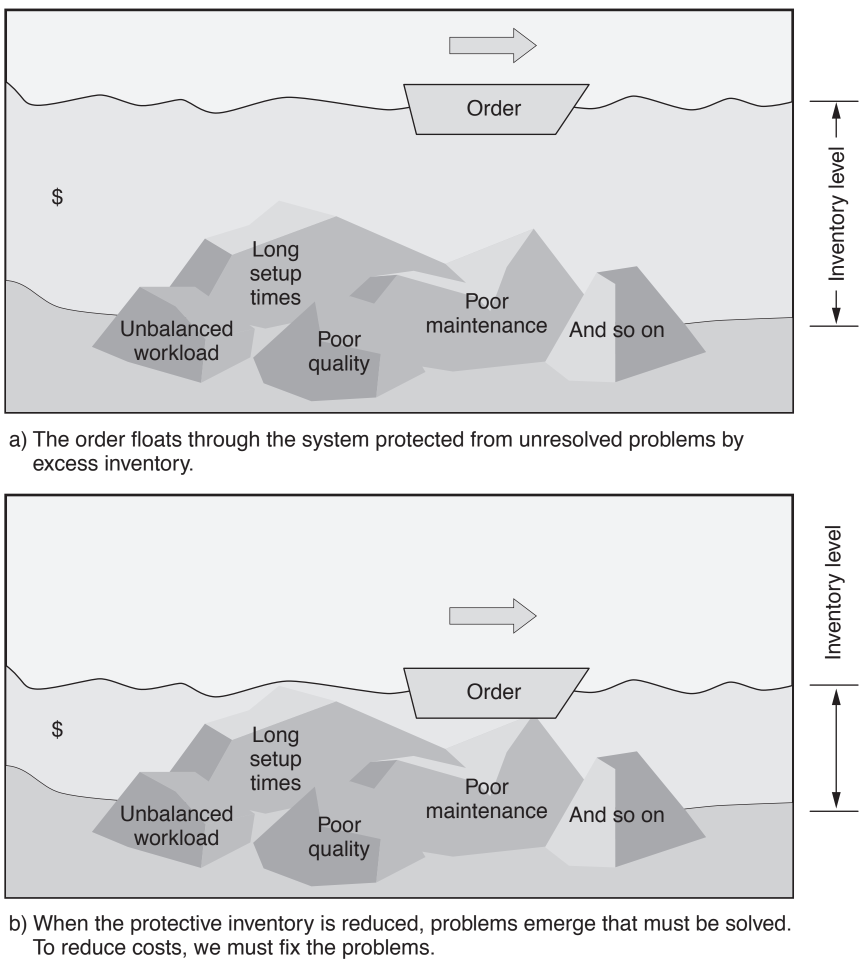


Figure 2.8 A sea of inventory often hides unresolved problems.

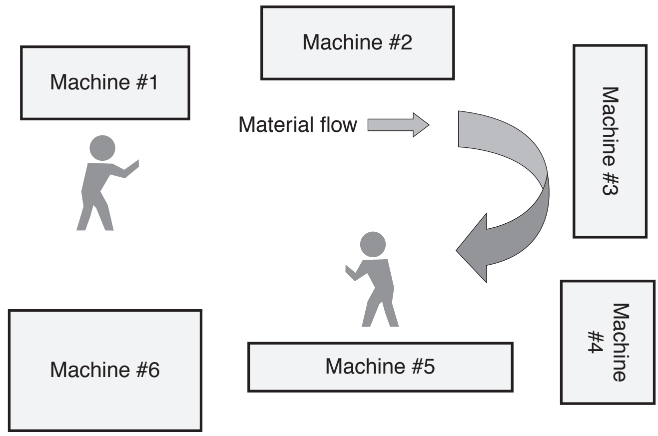


Figure 2.9 C-shaped manufacturing cell.

is used for one product or product family. This may mean having a manufacturing cell that contains several types of equipment, requiring personnel with multiple skills. Many companies have had success with cells that form a C or U shape, as shown in Figure 2.9, 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

Correcting defects is a non-value-added activity because the effort to fix the defective part is wasted. Typical causes of defects are poor process capability, inadequate 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

Extra processing is often difficult to recognize. Sometimes entire steps in the value chain are non-value-added. For example, a steel stamping operation produces a large volume of parts before they are scheduled for painting. This may require the parts to be dipped 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 production. This may require smaller batch sizes and improved communication procedures, among other things.

Lost Creativity

Lost creativity 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. 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 help the bottom line. These are the nontangible benefits of lean thinking.

Once all the different types of wastes are addressed in the process, lean implementation aims for perfection.

Perfection

By now you should 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 onetime effort. This is a continual learning process.

QUESTIONS

1. If you were to make a major purchase such as a new home, a solar electric system, or an automobile, how would you, as a consumer, perceive value?
2. Explain why "going to the gemba" is an important step before developing a value stream map.
3. Describe how the 5S tool can be applied in an office setting to improve productivity.
4. Identify examples of everyday poka-yoke that you have come across.
5. Describe how "standard work" plays an important role in lean implementation.

Chapter 3
Six Sigma Roles and Responsibilities

> Define and describe the roles and responsibilities of six sigma team members (i.e., individual team members, yellow belt, green belt, black belt, master black belt, process owner, champion, sponsor). (Understand)
>
> **Body of Knowledge I.C**

Six Sigma successes are not just about application of statistical tools. A strong Six Sigma organization is necessary for sustainable success. Without this, there will be no accountability to the investment made in employees in terms of training, resources spent, and a consistent approach of methodologies. Smaller organizations may combine some Six Sigma roles; however, the responsibilities of each role should be maintained. A typical large Six Sigma organization is shown in Figure 3.1.

One factor that has helped Six Sigma be successful is the structure it demands of organizations. Table 3.1 shows typical Six Sigma roles, the organizational members that typically fill the roles, their expected training or background, and the primary responsibilities of each role.

Organizations may employ program managers to assist the Master Black Belts in managing the overall Six Sigma implementation across the organization. The organization's finance department may also play a role by verifying the benefits claimed by the projects before the projects are presented to management.

QUESTIONS

1. You have been assigned to set up a Six Sigma organization for a company with fewer than 100 employees. Understanding that not every organization can afford a structure as identified in Figure 3.1, how will you structure your Six Sigma resources? What roles will you have? What will be their responsibilities?

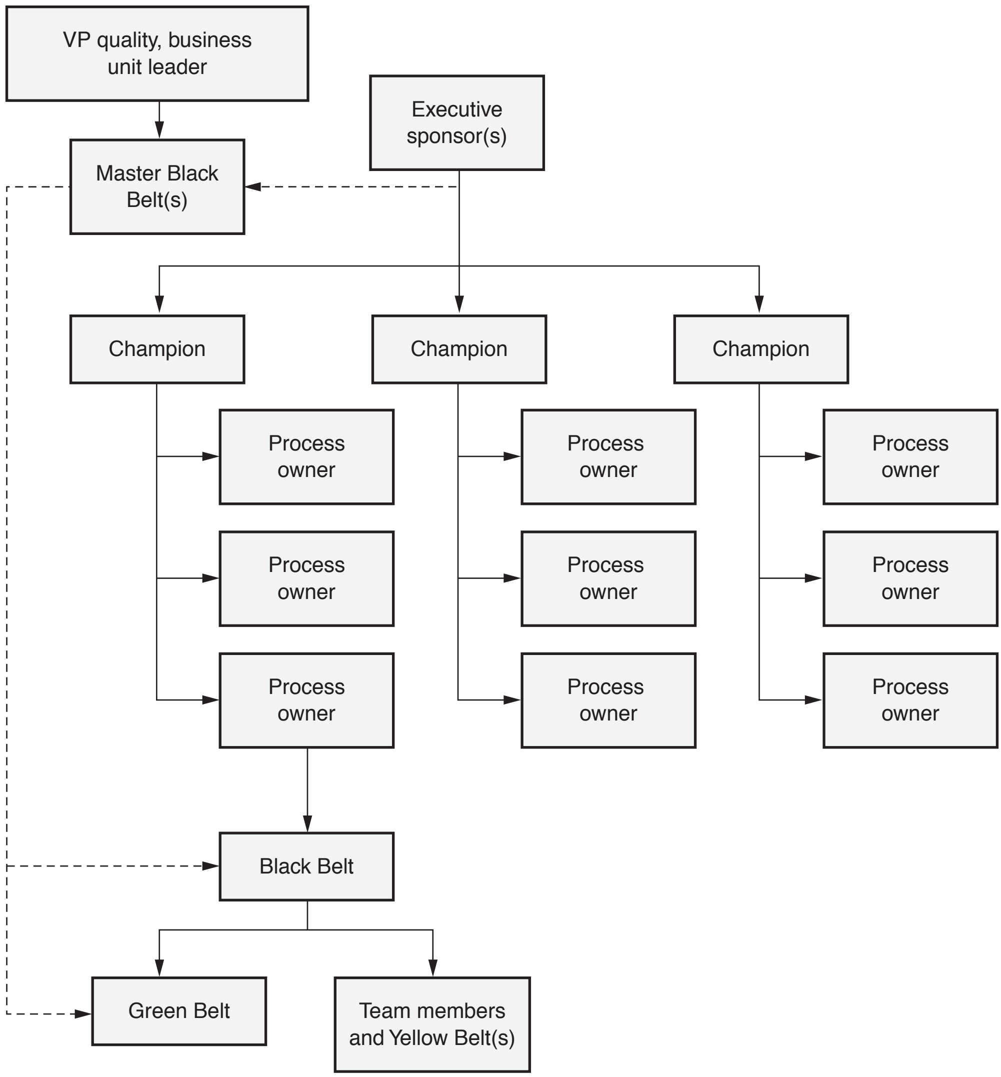


Figure 3.1 Typical large Six Sigma organization.

2. How do you ensure the continuity of the Six Sigma organization? Make recommendations.
3. What are the challenges of sustaining Six Sigma improvement projects without Six Sigma resources?

Table 3.1 Typical Six Sigma roles.

Role	Candidate	Training/background	Primary responsibilities
Executive sponsor	Business unit leader responsible for profit and loss (usually at director level or above)	Six Sigma concepts, strategies, overview, operational definitions.	• Set direction and priorities for the Six Sigma organization • Allocate resources for projects • Set Six Sigma vision and overall objectives for the program • Monitor the progress of the overall program • Initiate incentive programs • Reward successful projects
Champion	Typically upper-level managers	Six Sigma concepts, strategies, tools and methods, operational definitions. Emphasis on management tools. (ASQ Certified Six Sigma Yellow Belt)	• Liaise with senior management • Allocate resources for projects • Determine project selection criteria • Remove barriers hindering the success of the project • Approve completed projects • Implement change
Process owner	An individual responsible and accountable for the execution and results of a given process. The sponsor or champion could also be a process owner.	Six Sigma concepts, strategies, tools and methods, operational definitions. Emphasis on statistical tools. (ASQ Certified Six Sigma Yellow Belt)	• Select team members • Allocate resources for projects • Provide process knowledge • Review process changes • Approve changes/support change management • Implement change • Ensure that improvements are sustained

Continued

Table 3.1 *Continued.*

Role	Candidate	Training/background	Primary responsibilities
Master Black Belt	Individuals trained in Six Sigma methodologies, statistical tools, basic financial tools, change management, risk assessment, project management, executive communication, and well experienced in teaching, coaching, and mentoring Black Belts and Green Belts. This is always a full-time position.	Six Sigma BoK, lean enterprise synergy, finance for nonfinancial managers, risk assessment, project management, change agent skills, Master Black Belt train the trainer, presentation skills, communication skills, leadership skills, facilitation skills. (ASQ Certified Six Sigma Master Black belt)	• Coach Six Sigma Black Belts and Green Belts • Utilize the resources provided by management effectively • Formulate overall business strategy linking to Six Sigma program • Monitor project progress closely • Typically 15–20 projects overseen at a time • Provide coaching, mentoring for new Black Belts and Green Belts • Work with champions and process owners for selection of projects • Address issues of project stagnation • Remove barriers hindering the success of the project • Support as a subject matter expert for the organization • Review and approve completed projects • Share lessons learned with the extended team • Provide inputs to rewards committee
Black Belt	Individuals trained in Six Sigma methodologies, statistical tools, basic financial tools, change management, risk assessment, project management, and well experienced in managing Black Belt projects. This is always a full-time position.	Six Sigma Black Belt Body of Knowledge, lean enterprise synergy, finance for nonfinancial managers, risk assessment, project management, change agent skills, presentation skills, communication skills, leadership and facilitation skills. (ASQ Certified as Six Sigma Black Belt)	• Lead and manage Six Sigma projects • Utilize the resources provided by management effectively • Provide net present value, return on investment (ROI), payback calculations on projects • Work full-time on four to six projects per year • Monitor project progress closely • Follow DMAIC process, apply appropriate statistical methods • Work with champions, Master Black Belts, and process owners for selection of projects • Address issues of project stagnation/consult Master Black Belt • Remove barriers hindering the success of the project • Update and present project progress to management • Review completed projects • Share lessons learned with the extended team

Continued

Table 1.3 *Continued.*

Role	Candidate	Training/background	Primary responsibilities
Green Belt	Individuals trained in Six Sigma methodologies, basic statistical tools, and process improvement techniques. This is typically a full-time position. However, some organizations make this part of an existing job responsibility.	Six Sigma Green Belt BoK, lean enterprise synergy, presentation skills, communication skills. (ASQ Certified as Six Sigma Green Belt)	• Support Six Sigma projects with higher ROI • Lead smaller projects with moderate savings and ROI • Follow DMAIC process, apply appropriate statistical methods • Review the approach periodically with the experienced Black Belt and Master Black Belt • Provide inputs to Master Black Belt and Black Belt and process owners during selection of projects • Identify issues of project stagnation/consult Black Belt, Master Black Belt • Identify and report barriers hindering the success of the project • Share lessons learned with the extended team
Yellow Belt	Individuals trained to have awareness in Six Sigma methodologies, and understanding of basic statistical tools, and process improvement techniques. This is not a full-time position. Organizations make this part of an existing job responsibility. Management and Champion are also trained in Yellow Belt.	Six Sigma methodologies, principles, value, quality tools, process improvement, and teamwork. (ASQ Certified Six Sigma Yellow Belt)	• Support and contribute to Six Sigma projects • Provide inputs during project meeting, brainstorm ideas • Help collect data where responsible • Follow DMAIC process, apply appropriate tools • Review the approach periodically with the Green Belt and experienced Black Belt • Yellow Belts may be at a contributor to a project or a champion of a project
Project team member	Selected by process owner and trained in Six Sigma methodologies, quality, basic statistical tools, and process improvement techniques.	Six Sigma methodologies, quality tools, process improvement, teamwork.	• Support and contribute to Six Sigma projects • Participate in charter and scope definition • Provide inputs during project meeting, brainstorm ideas • Help collect data where responsible • Follow DMAIC process, apply appropriate tools • Review the approach periodically with the Green Belt and experienced Black Belt • Provide inputs to Green Belt and Black Belt and process owners during project

Chapter 4

Team Basics

> Identify the various types of teams that operate within an organization (i.e., continuous improvement, self-managed and cross-functional) and their value. (Understand)
>
> **Body of Knowledge I.D.1**

TYPES OF TEAMS

You are probably familiar with the saying "There is no 'I' in 'team.'" The essence of it is to imply that a team is a collective effort of individuals. To harness the best of each individual, the team members need to understand each other's strengths, roles, and responsibilities and the scope of the task. There are several books that go into detail about how to form a team, organize meetings, manage projects, and accomplish the desired goals. In the context of Six Sigma, we will cover areas important to a Six Sigma Yellow Belt. Protocols such as setting the team agenda, recording the minutes of the meeting with actions, sticking to meeting times, and enforcing meeting attendance need to be followed for an effective team meeting. An initial meeting to kick off the team with introductions and a high-level discussion of the goal, objective, milestones, and so on, will provide an opportunity for the team members to get to know each other and understand the expectations. A team must have an agenda, but it can be flexible.

Some teams have their team goals, objective, and scope/boundaries visibly displayed in every meeting to keep the members on track. Management presence during kickoff and frequently during the project helps enforce the importance of the team objective.

Team Formation

A team usually comprises five to seven members with complementary skills to achieve the goals and objectives of the team. Team composition should be driven by the size and scope of the project; it is possible to have a team of two or three individuals for a smaller project and a large team with subteams for a bigger project. The team includes subject matter experts and stakeholders. Subject matter experts sometimes remain outside the team as resources or extended team members. Stakeholders are always part of the team. The team will not be able to implement its ideas and solutions without having stakeholders or their representation on the team. Teams smaller than five individuals are easier to manage than larger teams, but the opportunity for interaction and ideas is reduced. Teams larger than seven individuals produce a lot of interaction that can be counterproductive to a team's progress. Teams with greater diversity tend to produce better interactions between team members. In some cases, teams bring in individuals who are neither subject matter experts nor stakeholders but outsiders. The outsider helps the team ask questions that were never explored by the team members closest to the process. However, the use of outsiders needs to be moderated, as the outsider might ask too many questions and frustrate the core members by slowing down the progress. Typically, cross-functional Six Sigma teams are formed to address the issues from every angle.

Virtual Teams

Virtual teams are an interesting evolution in the past decade due to the development of technology in communication tools and the Internet, which have led to the ability to meet and share data virtually. Virtual teams enable people from all over the globe to meet via teleconferences, videoconferences, and Internet tools such as shared computers. The virtual team has many benefits, the most prevalent being reduced administrative and logistical costs and real-time data sharing and updating. However, virtual teams also face challenges that include slowing of the progression of normal team building inability to get true commitment and buy-in, and the potential for miscommunication—especially with teleconferencing, as the important factor of nonverbal communication is lost. Additionally, technology-related issues can cause distraction and reduce the effectiveness of the meeting. Virtual teaming has its place in every organization and can be very effective, especially if team members are familiar with each other. Hence, it may be beneficial for the team to meet face to face at some period during the project. This relationship can be helpful to project continuity.

Continuous Improvement Teams

Team members are often from the same process with varying responsibilities. The team is given a clear goal by management to improve yield, productivity, safety, and so forth. The team appoints a leader (process owner), meets regularly, applies continual improvement tools, and reaches the goal. Once the goal is achieved, the team goes to work on the next goal.

Self-Managed Teams

A self-managed team is a group of independent team members who plan, direct themselves, and operate with a set of procedures toward a common goal. Team harmony is achieved after the team members have worked with each other on other projects and have appreciation for each other's skill and disposition. Projects and purpose are carefully chosen for self-managed teams. The team members have proven effectiveness.

Cross-Functional Teams

Product development, continual improvement, and problem-solving projects require a cross-functional team to be assembled. Representatives from all the different functions will be required in order to obtain the knowledge and experience needed for a project. Cross-functional team members will be needed in order to implement any solution the team comes up with. Cross-functional teams have several advantages in terms of efficiency and results, but they also have challenges. Priorities for cross-functional members may be different. They may not feel the same sense of urgency and provide the same level of commitment as a team whose members are from one business function. The team leader, with management support from the sponsor of the project, should set the tone for the common purpose.

> Describe the various stages of team evolution: forming, storming, norming, performing, and adjourning. (Understand)
>
> **Body of Knowledge I.D.2**

STAGES OF DEVELOPMENT

Team Stages and Dynamics

It is important to understand team dynamics and performance. Many projects have failed miserably because of a lack of teamwork and not understanding the roles and responsibilities of the team members. It is important to note that in those failed projects, the team members were technically competent and had complementary skill sets to succeed in those projects.

According to B. W. Tuckman, teams typically go through the stages of *forming, storming, norming, performing*, and *transitioning* (or adjourning).[1] We will explore each stage and identify the appropriate management approach required for that stage.

STAGE 1: FORMING

1. Team members are getting to know each other.
2. The group is immature.
3. There is a sense of belonging to the group.
4. There is pride in membership with the group.

5. Group members try to please each other.
6. Members tend to agree too much on initial discussion topics.
7. Not much work is accomplished.
8. Members are orientated on the team goals.
9. Members understand the roles and responsibilities.

STAGE 2: STORMING

1. Team members voice their ideas.
2. There is an understanding of the scope and members' roles; responsibilities will be put to test.
3. Ideas and understanding start to conflict.
4. Disagreements start to slow down the team.
5. Not much work is accomplished.
6. This step presents a necessary evil that every team member has to go through to position themselves on the team.
7. Too much disagreement can completely stall team progress.

STAGE 3: NORMING

1. Team members resolve their conflicts.
2. Team members agree on mutually acceptable ideas to move forward.
3. Some work gets accomplished.
4. Members start to function as a team.
5. Team members start to trust each other and share their ideas and work products without hesitation.

STAGE 4: PERFORMING

1. The team is effective, skills complement, and synergy is created.
2. Team members realize interdependence.
3. Team members develop the ability to solve problem as a team.
4. Large amount of work gets accomplished.

STAGE 5: TRANSITIONING (OR ADJOURNING)

1. The team is disbanded.
2. Team members go on with other activities of their work.
3. If the project is continued with additional scope, team members may be changed.

4. The team dynamic changes and tends to go back to one of the earlier stages.
5. Major changes can result in going back to forming stage.

This is the typical evolution of team stages. Depending on the organization's culture, some stages may be shorter or longer, but the team still goes through them.

It is healthy for the team to go through these stages as it sets ground rules and expectations for team members. Team maturity, complexity of the task (project), and team leadership also have an impact on the stages.

Recognition

Recognition of the team's work is the often forgotten piece of team dynamics or, rather, is taken for granted. Even though team members are compensated monetarily for their time and skill, they should be recognized. Teams can be recognized in many ways, from a simple pat on the back by senior management to thank-you notes, bulletin boards, organization-wide e-mails, newsletters, all-employee meetings, certificates of accomplishment, bonuses, stock options, and so on.

Team Leadership

The team leadership may vary depending on the maturity of the team and the stage the team is at based on the leader's perception. Examples of leadership activities during each of the stages include:

Forming. Appropriate leadership style is *directing*:

— Leader welcomes and encourages the team

— Leader explains the roles, responsibilities, and goals of team members

— Leader instructs the team as to what to do when, where, and how

— Leader provides close supervision, exhibits directive behavior

— Leader listens to team's feedback

— Leader identifies opportunities for developing skills to meet team goals

Storming. Appropriate leadership style is *coaching*:

— Leader continues close supervision, exhibits directive behavior

— Leader also exhibits supportive behavior

— Leader increases the listening level to solicit the team's feedback

— To keep the storming at an acceptable level (not detrimental to the task at hand), the leader may bring in a facilitator or use conflict resolution approaches

Norming. Appropriate leadership style is *supporting*:

— Leader reduces the level of directive behavior and increases the level of supportive behavior

— Leader encourages the team on decision-making responsibilities

— Leader helps the team move to the performing stage before it can revert to an earlier stage

— Leader emphasizes ground rules, scope, and roles and responsibilities

Performing. Appropriate leadership style is *delegating*:

— Since the team is mature, the leader reduces the levels of directive and supportive behavior in day-to-day functions

— Leader continues to monitor the goals and performance of the team

— Leader watches for any disruption in dynamics due to major changes in the organization

Negative Team Dynamics

If a team has several negative dynamics, this is more a reflection on the organizational culture than on the personalities of the individuals. If something is "acceptable" within the organization as a norm, that becomes the way of running the business. In other words, the organizational culture becomes the "enabler" of the many team problems that organizations face.

Negative dynamics in the team can:

- Have a negative impact on team member motivation
- Hurt a team member's ego and self-esteem
- Intimidate team members
- Reduce the self-confidence of others
- Increase stress and exhaust patience
- Increase feelings of insecurity
- Foster a lack of morale

As a result, unchecked or unaddressed negative team dynamics may cause:

- Goals and objectives of the project/task to not be met
- Targets to be frequently revised to the team's advantage
- The project to be cancelled
- Project milestones and deadlines to be missed
- Poor utilization of project resources
- The project to overrun its cost targets
- Turnover of key project team members

Table 4.1 outlines common negative team dynamics and possible countermeasures. Chapter 1 of *The Team Handbook* discusses additional facilitation tactics.[2]

Table 4.1 Common negative team dynamics and potential countermeasures.

Negative dynamic	Symptoms	Probable causes	Potential countermeasures
Overbearing member(s)	Team interaction is limited to a few individuals. The rest of the team is always in listening mode rather than participating in the discussion.	Team is composed of a few influential members (senior management staff, founders, inventors), members with legitimate authority (investor, major shareholder, owner), subject matter experts, and so on. This may intimidate other team members, who hesitate to voice their opinions.	With the support of the influential team member, the team leader reinforces round-robin voicing of opinions, using methods like nominal group technique, conducting the meeting in a more informal setting, keeping experts and influential members as an extended team, and so on.
Dominant member(s)	Meeting discussion is chaotic and difficult to listen to or understand. Only a few members dominating the entire discussion.	Dominant team members keep interrupting the conversation of other team members.	Structure the agenda to provide equal participation for all team members. Effective moderation by team leader allows other team members to finish their thoughts. Team leader initiates round-robin to provide opportunity for every team member to be heard.
Floundering	Team is currently proceeding or performing in an unsteady, faltering manner.	Lack of team direction. Some teams have high-profile team leaders from the organization, but they hardly ever attend meetings or team discussions. The organization is going through major changes, and no one is clear about the future of the team. Team members are overwhelmed. This can be due to multiple reasons. The organization may be going through major changes: leadership, downsizing, mergers and acquisitions, offshore transfers, and so on. Postponing of team decisions. This is related to lack of direction from the team leadership. If there is no clear direction, decision making gets difficult.	During early stages of the team, more direction is required. Team leadership should be visibly present during the team meetings and decisions. Team leadership should keep the team focused by not getting distracted by events happening within the organization. Team leaders should address the concerns of the team members but not allow the team agenda to be hijacked by other events. Reinforce management support and commitment when team starts to challenge the purpose of the team.

Continued

Table 4.1 *Continued.*

Negative dynamic	Symptoms	Probable causes	Potential countermeasures
Reluctant participants	Lack of participation, noncommittal feedback. Basically showing disinterest.	Team member may not have any stake in the team's outcome. Intimidated by other team members or leaders. In the process of moving out of the current job function or organization. Fear of losing job or position by voicing opinions.	Team leaders support the team members' active participation and protect the team members voicing their opinions.
Unquestioned acceptance of opinions as facts	Members present information without backing up data or analysis. Members present unfounded assumptions.	Organizational culture. Lack of management by facts.	Team leader requests supporting data, analysis, and conclusions that are statistically valid. Question the assumptions behind the analysis.
Groupthink	No public disagreements. Doubts expressed in private discussions. There are several other classical symptoms identified by researchers.	Members fear group cohesiveness will be at stake if there are any disagreements. Putting group harmony as paramount.	Bring independent members from outside to participate. Rotate roles and responsibilities of members at milestones. Management by fact.
Feuding	Hostilities resulting in heated arguments, slowed progress, low morale of the team.	Conflict resolution not effectively handled by the team leadership. Lack of mutual respect between team members. Team operating ground rules not enforced.	Confront the adversaries offline and not in the team meeting. Confronting in public can worsen the situation. Enforce discipline and emphasize mutual respect among team members. Restate the objective of the team as main focus.
Rush to accomplishment	Incomplete data collection. Inconsistent analysis. Trying to get conclusion faster.	Team under unrealistic deadline. Untrained team members. Looking for short-term gains.	Team leadership asks for data collection, analysis, and statistical significance. Ask for alternate solutions. Revise the deadline to a more realistic one based on resources.

Continued

Table 4.1 *Continued.*

Negative dynamic	Symptoms	Probable causes	Potential countermeasures
Attribution	Members make casual references. Members don't seek explanations, preferring psychological and emotional judgments.	Similar to "rush to accomplishment" causes.	Team leaders challenge the assumptions made by team members. Use devil's advocate approach. Ask for analysis behind the conclusions drawn.
Discounting	Members' opinions are ignored. Members do not seem to listen to each other. Sarcasm, low team morale.		Encourage mutual respect. Enforce discipline. Ask for clarification from the members providing opinions.
Digressions and tangents	Discussion straying outside meeting agenda. Distractions. Meeting time not properly utilized; little is accomplished.	Organization going through major change. Cultural issues. Lack of focus from leadership.	Enforce compliance with agenda items and time allotment. Restate meeting ground rules. Redirect the discussions.

> Define and apply decision-making tools such as brainstorming, multivoting, and nominal group technique (NGT). (Apply)
>
> **Body of Knowledge I.D.3**

DECISION-MAKING TOOLS

Brainstorming

Brainstorming is a process where a team develops as many ideas concerning a topic as possible, using various creative methods. Brainstorming is a powerful technique for soliciting ideas, and it is used extensively in many improvement activities at every stage of improvement or problem solving. This tool intentionally encourages divergent thinking through which, hopefully, all possible causes are identified. This is a team exercise and requires a good facilitator to get the ideas flowing. Brainstorming has two phases: the creative phase, in which a large number of ideas are generated, and the evaluation phase, in which the ideas generated are looked at for usefulness or applicability. The two phases should be separated by a time break, as different parts of the brain are used in each phase. At a minimum, a 10-minute break should be taken after the creative phase versus going directly to the evaluation phase.

Criticisms or other distractions are not allowed during the creative phase. Team members should keep their minds open to all the possibilities no matter how wild the idea. The goal is to get as many ideas as possible. Facilitation can be used during the creative phase, but freewheeling also works well. Brainstorming is effectively performed with the help of a trained facilitator. The facilitator's job is to enforce ground rules and encourage ideas. A common tendency of brainstorming teams is to criticize the ideas instantly and discard them during the session. This will discourage team members from contributing for fear of being rejected. Team members must remember that there are no bad ideas. At this stage, quantity of ideas is given priority. A typical brainstorming session can generate between 25 and 40 ideas. If a flip chart is used to record ideas with a large group, two or more individuals should be used to capture all the ideas as they develop. You could also have each person say what they are thinking and then have them or someone else record the idea on a sticky note and put it on the wall. Some basic guidelines that should be followed in the creativity phase of brainstorming include:

- No criticism, compliments, or questions
- Wild ideas are welcome
- Don't wait
- Quantity is important (versus quality)
- Hitchhike—build on previous ideas

During the evaluation phase, it is best to have a facilitator work with the group to look over the ideas in sequence. There are many ways to evaluate the ideas generated. One good starting point is to organize the list of things into like groups or categories (i.e., build an affinity diagram; see Chapter 7, Figure 7.2). The caution here is to not get overly critical, as there may be something in one of those "crazy" ideas that might actually work for the given situation. This is often true because of new technology or different ways of doing things that are not common in our organizations. To get the most out of brainstorming, before starting the activity review, look over the following idea-stopping responses with the team:

- Don't be ridiculous
- Let's shelve it for right now
- It won't work here
- Our business is different
- Let's think about it some more
- We did all right without it
- It's too radical a change
- Management won't like it
- Where did you dig up that idea?
- It's not practical
- It's too expensive
- You can't be serious
- You can't do that
- The technology will not allow that
- Where will you get . . .?
- We've never done it before
- I have something better
- It's too risky
- Let's be sensible
- We'll never get it approved
- The employees won't like it
- It's good, but . . .
- Let's check on it later
- It's too much work
- Let's get back to reality
- That's been tried before

- That's not my job
- You do not know how we do things around here
- That's too high-tech for us
- It will never work

In practical application, the team identifies the subject or problem at hand and writes it down on a whiteboard. It is important to clearly define the problem. This will keep the ideas on topic. For an issue that is unfamiliar to the team, it is acceptable to keep the scope open so that a wide range of ideas are generated. The team leader explains the problem or subject to the team members.

The following example topics have the scope defined to facilitate the majority of ideas focusing on the defined area:

- Contamination of polished surfaces before optical subassembly
- Low attendance at ASQ section program meetings
- Food menu for Thanksgiving dinner

Following are examples with the scope wide open:

- Global warming
- Unemployment
- Organizational culture

The team is given a few minutes to think about the subject. In structured brainstorming the team leader opens up a round-robin discussion. This way everyone gets the opportunity to contribute. If someone doesn't have an idea at this time, they are allowed to pass and contribute during the next round. Team members are not allowed to criticize each other or evaluate the ideas at this stage. The individual recording the ideas can ask for clarity on an idea and phrases it the same way as the idea contributor. Rephrasing without the consent of the idea owner is not allowed. Everyone is allowed one idea at a time. Some members will have the urge to provide multiple ideas during their turn. The team leader should facilitate such situations. Members are allowed to develop an idea already cited by a fellow member.

Quantity is more important than quality, so the team leader should encourage the team to keep the ideas flowing. All ideas are recorded on a whiteboard or flip chart.

We will now look at an example of defined-scope brainstorming: How can member attendance of ASQ section program meetings be improved? (problem rephrased as a question). Every major city in North America has a local ASQ section run by volunteers. A benefit of this section is the monthly program meeting. Unfortunately, these meetings draw a very low attendance (about 7%–10%) of members from the region, with at least 20% of the members attending once throughout the year.

The program chair (responsible for ASQ section monthly meetings) leads the brainstorming session, and the section chair may act as a facilitator. A team has been assembled with other section executives, past section chairs and/or executives, section senior members, and members randomly selected from the membership database.

One of the members volunteers as a recorder, and the team is given three minutes to think about the subject—How can member attendance of ASQ section program meetings be improved?—in a focused manner. The session starts in a round-robin style and ideas begin flowing. Team members come up with the following:

1. Bring in reputed speakers
2. Present topics that are current
3. Provide value for time and money
4. Keep program interactive—have a debate, quiz, etc.
5. Survey members for desired topics
6. Rotate program locations based on member concentration
7. Conduct some programs in the organizations with the most members
8. Do not charge for meeting
9. Offer refreshments (e.g., pizza, snacks, sandwiches, coffee)
10. Offer time for networking
11. Have section chair and executives mix with members and attendees during break (rather than talking among themselves as a small group)
12. Check weather forecast before planning meetings
13. Inform members of other section events
14. Conduct less frequent but more effective meetings
15. Do not waste meeting time with logistics issues—be prepared
16. Offer the meeting virtually—webcast, teleconference
17. Draw name cards from fishbowl and offer a small gift
18. Make the process easier for claiming recertification units for program attendance
19. Present two diverse topics
20. Provide carpool to meeting location for new or potential members
21. Liaise with other professional organizations to offer combined program meeting
22. Post meeting information at universities to attract students
23. Conduct some meetings on the local community college or university campus to attract students
24. Provide "back to basics" programs with applications for students and small business owners

25. Interview a random sample of members who have never attended a meeting and find out why
26. Interview a random sample of members who have attended every meeting and find out why
27. Introduce first-time attendee members/nonmembers in the group to make them feel welcome
28. Have program chair survey every program for attendee satisfaction and review feedback
29. Appoint a marketing chair to reach a wider member base and potential new members
30. Keep the section website updated and easily accessible
31. Upload archive presentations to the website
32. Communicate at least twice about the monthly program—three weeks before and one week before
33. Announce and recognize newly certified professionals
34. Record and archive the program events and make them available to local libraries and online for free

Wow, isn't this quite a collection of ideas? The team now reviews the ideas for redundancy and feasibility and then prioritizes them. The selected ideas are categorized under one of the following: personnel (man), machine, material, methods, measurement, environment. Some teams include measurement under methods. Cause and effect diagrams can be tailored to the operation (e.g., software development uses people, processes, products, resources, miscellaneous).

It is not uncommon for the team to continue brainstorming in a second sitting to add more ideas to the existing list. Some teams will break after a few rounds and revisit the list with any additional thoughts. However, a second round of brainstorming should not be prolonged, as the team may get bored and ideas will start to be counterproductive or too critical.

There are other team tools used to take these ideas to the next step:

- *Multivoting*, to short-list the ideas as a group
- *Cause and effect diagram*, to assign each idea to one category, namely, personnel, machine, material, method, measurement, and environment, and further analyze why

Nominal Group Technique

Nominal group technique (NGT) is a type of brainstorming but with limited team vocal interaction—hence the term "nominal." This technique is applied in groups with both very vocal members and less vocal members, to encourage equal participation from all members, or with a controversial or sensitive topic, and so on. This technique helps alleviate peer pressure and reduces the impact of such pressure on the generation of ideas.

As in brainstorming, the facilitator explains the rules, and the team leader presents the topic to the assembled members. The team is given 10–15 minutes to silently sit, think, and generate ideas.

No verbal interactions are allowed during the session. At the end of the session, the member ideas are collected and posted where all can read them. The members may also read the ideas aloud one by one in a round-robin format. At this stage no judgment or criticism is passed. The ideas are simply written down. The members are allowed to expand on existing ideas, provide clarity, and eliminate redundancy during the consolidation. For a controversial or sensitive subject, the team leader may opt to collect the ideas and write them down on the board, maintaining anonymity of the contributors.

Multivoting

Multivoting complements NGT and can also be successfully used with brainstorming results. Even though this tool is typically used in combination with NGT, it can be a technique on its own. The consolidated ideas are numbered or lettered, and the team members are asked to prioritize the top 5 or 10 items that can be of significant influence on the problem. The team members are given 5–10 minutes to prioritize, and the results are tabulated.

Let's return to the example of how to improve attendance at ASQ section program meetings. The members have been asked to submit and prioritize ideas. As we have discussed, the diversified member group provides 34 ideas. Even though many of those ideas are good, the section may not have resources to address them all at one time. The section chair wants to select the five most important ideas to address in the next three years, and implement them in order of priority.

Each team member selects the five most important ideas by placing a check mark by the idea. It is important for the facilitator to restate the objective and refocus the team to select ideas from the ASQ section point of view. If this facilitation is not done, you may end up with multiple ideas with an equal number of check marks. Once this is done and you have the five ideas that most team members have selected as significant for improving the attendance of a section program, the prioritization process has begun. This can be done through either a non-weighted (ranking) or a weighted approach.

The members have selected the following ideas, categorized into five themes, as having the most significant impact on improving section attendance:

1. *Value.* Bring in reputed speakers and present topics that are current
2. *Logistics.* Rotate program locations based on member concentration
3. *Affordability.* Do not charge for meeting and offer refreshments (e.g., pizza, snacks, sandwiches, coffee)
4. *Outreach.* Conduct some meetings on the local community college or university campus to attract students
5. *Communication*. Send e-mails twice per month, update section calendar event web page

Venue: Caribou meeting room
Date: 3-Feb-15
Subject: How can member attendance of ASQ section programs be improved?
Scale: 1 (least important) to 5 (most important)

	Member 1	Member 2	Member 3	Member 4	Member 5	Member 6	Member 7	Member 8	Member 9	Total
A	5	2	4	5	5	2	4	5	5	37
B	2	4	3	3	4	4	3	3	4	30
C	1	5	5	4	3	5	5	4	3	35
D	3	3	1	2	2	3	1	2	2	19
E	4	1	2	1	1	1	2	1	1	14

Figure 4.1 Multivoting ranked approach example.

The multivoting ranked approach outcome is shown in Figure 4.1.

In the multivoting weighted approach, the team rates rather than ranks the choices. This is like the $100 or 100 points approach, where the team member is asked to split $100 or 100 points among five choices. The multivoting weighted approach outcome is shown in Figure 4.2. As shown in Figures 4.1 and 4.2, the two approaches produce similar rankings in this example. However, this is not always the case, which is why using both approaches can help a team focus on the most critical items. If two items have values that are close to each other, another round of voting can be conducted to select a clear winner.

Note: While this example is not targeted to a specific ASQ section, the problem chosen for this example and the ideas generated are realities for most ASQ sections. The top choices and ranking were created to demonstrate the example rather than to provide solutions to the existing problem.

Venue: Caribou meeting room
Date: 3-Feb-15
Subject: How can member attendance of ASQ section programs be improved?

	Member 1	Member 2	Member 3	Member 4	Member 5	Member 6	Member 7	Member 8	Member 9	Total
A	30	20	25	35	20	25	25	35	30	245
B	15	25	20	20	25	20	20	20	15	180
C	10	30	30	25	30	30	30	25	10	220
D	20	15	10	15	15	10	10	15	20	130
E	25	10	15	5	10	15	15	5	25	125

There is NO ranking scale applicable to this approach. The column total should add up to 100 for all individual columns and the relative importance of A to E to be understood by the points allotted by each member (from that member's point of view). Overall relative importance is understood from reviewing the "Total" column. Based on consolidated input from all members, in this example, A is most important, followed by C, B, D, and E.

Figure 4.2 Multivoting weighted approach example.

> Explain how teams use agendas, meeting minutes, and project status reports, and how they support project success. (Apply)
>
> **Body of Knowledge I.D.4**

COMMUNICATION METHODS

Team projects are reviewed through meetings. Effective meetings are key to project success as they provide continual updates of information and action to the team members.

We need to be asking ourselves:

- Are we discussing the right topic?
- Do we have the right audience?
- Do we have actionable discussions?
- Do team members who attend the meeting know what they should do?
- Was the time spent productive and worthwhile?

Why are meetings not productive?

- Overwhelming information
- Too many presentation slides
- Information unrelated to the agenda
- Attendees not well prepared
- Sending delegated attendees on short notice
- Too many side conversations
- Attendees using their smartphones to check e-mail and messages
- Remote attendees calling in through virtual meeting infrastructure may be multitasking
- Preparations are being made for the next meeting while still in the current meeting
- Getting in arguments over "how to" while the meeting is still focused on "what to"
- No actionable discussions—groupthink and philosophical agreements

A worldwide productivity survey conducted by Microsoft revealed the following:

- "People work an average of 45 hours a week; they consider about 17 of those hours to be unproductive (U.S.: 45 hours a week; 16 hours are considered unproductive)."

- "People spend 5.6 hours each week in meetings; 69 percent feel meetings aren't productive (U.S.: 5.5 hours; 71 percent feel meetings aren't productive)."[3]

Ineffective meetings continue to haunt every organization as a major productivity detractor. The organization's culture may contribute a lot to the ineffective meetings. Taking a disciplined approach to meetings will help address many of the issues mentioned earlier. Meetings have to be conducted periodically to ensure continuity.

An effective meeting includes the following:

- *Agenda.* Meetings should not be initiated or attended without a clear agenda. The meeting subject is not the agenda. The agenda should be itemized: meeting subject, items required to be discussed, item presenters, and time allotment. Without a clear agenda and time allotment for agenda items, the meeting can easily get out of control and become unproductive. If it is a project meeting, the scope has to be presented to the team members to ensure that there is no scope creep.
- *Meeting logistics.* This includes meeting room (for face-to-face meetings), virtual call-in infrastructure, and video capability.
- *Meeting minutes.* The meeting minutes are a record of the meeting. Minutes are essential to ensure the key decisions made and the actions agreed on by the team members are formally recorded and keep the team members accountable. The minutes should be well drafted and unambiguous, and they should indicate the date and time of the completed meeting, meeting host, attendees, topics covered, decisions made, actions assigned (what, who, when), minutes reviewed and approved, and scribe name. One might also include "parking lot" items that are pending detailed discussions. Meeting minutes are important to project continuity.
- *Project status report.* This is a periodic status report created by the project manager or team leader and circulated to all team members and management to list the status of the project, upcoming milestones, risks, and mitigation plans. Any unacceptable project variances and risks are addressed early in the project by reviewing the status reports and taking appropriate actions.

QUESTIONS

1. Why is "storming" a necessary evil in the team stages? Discuss your experience in a team that went through the storming stage. Describe any lessons learned.
2. Why is recognition of a team after the successful completion of a project highly recommended? What are your recommendations for recognition for a Six Sigma team?
3. Discuss the effect of "groupthink" in a meeting. How do you ensure due diligence?

4. A team struggling to meet project milestones has repeatedly requested extensions from the management. This is a high-stakes project and the revenue stream is dependent on project success. You have been asked by your Black Belt to conduct a brainstorming session to identify causes of the team's lack of progress. Discuss the issue with your participants and put together a list of plausible causes. Apply the multivoting approach as well.
5. List the major causes of ineffective meetings in your organization. Research best practices for improving meeting effectiveness and share with your participants.

Part VI

Appendices

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

A. 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.

B. 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.

C. 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

ASQ Certified Six Sigma Yellow Belt (CSSYB) Body of Knowledge (2022)

The topics in this Body of Knowledge include additional detail in the form of sub-text explanations and the cognitive level at which test questions will be written. This information will provide guidance for the candidate preparing to take the exam. The subtext is not intended to limit the subject matter or be all-inclusive of what might be covered in an exam. It is meant to clarify the type of content to be included in the exam. The descriptor in parentheses at the end of each entry refers to the maximum cognitive level at which the topic will be tested. A complete description of cognitive levels is provided at the end of this document.

I. *Six Sigma Fundamentals* (20 Questions)

A. *Six sigma foundations and principles.* Describe the purpose of six sigma (reducing variation), its methodology (DMAIC) and its evolution from quality. Describe the value of six sigma to the organization as a whole. (Understand)

B. *Lean foundations and principles.* Describe the purpose of lean (waste elimination) and its methodologies (just-in-time, poka-yoke, kanban, value-stream mapping). Describe the value of lean to the organization as a whole. (Understand)

C. *Six sigma roles and responsibilities.* Define and describe the roles and responsibilities of six sigma team members (i.e., individual team members, yellow belt, green belt, black belt, master black belt, process owner, champion, sponsor). (Understand)

D. *Team basics*

1. *Types of teams.* Identify the various types of teams that operate within an organization (i.e., continuous improvement, self-managed and cross-functional) and their value. (Understand)

2. *Stages of development.* Describe the various stages of team evolution: forming, storming, norming, performing, and adjourning. (Understand)

3. *Decision-making tools.* Define and apply decision-making tools such as brainstorming, multivoting, and nominal group technique (NGT). (Apply)

4. *Communication methods.* Explain how teams use agendas, meeting minutes, and project status reports, and how they support project success. (Apply)

E. *Quality tools and six sigma metrics*

1. *Quality tools.* Select and use these tools throughout the DMAIC process: Pareto charts, cause and effect diagrams, flowcharts, run charts, check sheets, scatter diagram, and histograms. (Apply)
2. *Six sigma metrics.* Select and use these metrics throughout the DMAIC process: defects per unit (DPU), defects per million opportunities (DPMO), rolled throughput yield (RTY), cycle time, and cost of poor quality (COPQ). (Apply)

II. *Define Phase* (14 Questions)

A. *Project identification*

1. *Voice of the customer.* Define the voice of the customer and describe how customer needs are translated into quantifiable, critical-to-quality (CTQ) characteristics. (Understand)
2. *Project selection.* Describe how projects are identified and selected as suitable for a six sigma project using the DMAIC methodology. (Understand)
3. *Stakeholder analysis.* Identify end users, subject matter experts, process owners and other people or factors that will be affected by a project, and describe how each of them can influence the project. (Understand)
4. *Process inputs and outputs.* Use SIPOC (suppliers, inputs, process, outputs, customers) to identify and define important elements of a process. (Apply)
5. *Supply chain management.* Understand supply chain management and how it relates to project management. (Understand)

B. *Project management (PM) basics*

1. *Project charter.* Describe the purpose of a charter and its components: problem statement, project scope, baseline data, and project goal. (Understand)
2. *Communication plan.* Explain the purpose and benefits of a communication plan and how it can impact the success of the project. (Understand)
3. *Project planning.* Define work breakdown structure (WBS) and Gantt charts and describe how they are used to plan and monitor projects. (Understand)

4. *Project management tools.* Select and use various PM tools: activity network diagrams, affinity diagrams, matrix charts, relations charts, and tree diagrams. (Understand)

5. *Phase reviews.* Explain how tollgate or phase reviews are used throughout the DMAIC lifecycle. (Understand)

III. *Measure Phase* (15 Questions)

A. *Basic statistics.* Define, calculate, and interpret measures of central tendency (mean, median, mode) and understand measures of dispersion (standard deviation, range, variance). (Apply)

B. *Data collection*

1. *Data collection plans.* Describe the critical elements of a data collection plan, including an operational definition, data sources, the method to be used for gathering data, and how frequently it will be gathered. Describe why data collection plans are important. (Understand)

2. *Qualitative and quantitative data.* Define and distinguish between these types of data. (Understand)

3. *Data collection techniques.* Use various data collection techniques, including surveys, interviews, check sheets, and checklists to gather data that contributes to the process being improved. (Apply)

C. *Measurement system analysis (MSA)*

1. *MSA terms.* Define precision, accuracy, bias, linearity, and stability, and describe how these terms are applied in the measurement phase. (Understand)

2. *Gauge repeatability & reproducibility (GR&R).* Describe and distinguish between repeatability and reproducibility and describe how and why GR&R is used in the measurement phase. (Understand)

IV. *Analyze Phase* (15 Questions)

A. *Process analysis tools*

1. *Lean tools.* Define how 5S and value analysis can be used to identify and eliminate waste. (Understand)

2. *Failure mode and effect analysis (FMEA).* Relate the elements of severity, opportunity, and detection, how they are used to calculate the risk priority number. Demonstrate how FMEA can be used to identify potential failures in a process. (Apply)

B. *Root cause analysis.* Describe how the 5-whys, process mapping, 8D, force-field analysis and matrix charts can be used to identify the root causes of a problem. (Understand)

C. *Corrective action*. Explain and apply elements of the corrective action process: identify the problem, contain the problem (interim action), determine the causes of the problem and propose solutions to eliminate it or prevent its recurrence (permanent action), verify that the solutions are implemented, and confirm their effectiveness (validation). (Apply)

D. *Preventive action*. Explain and apply elements of a preventive action process: understand various process analysis techniques to identify potential failures, defects, or process deficiencies; improve the process (e.g., understand error- or mistake-proofing devices or methods, initiate procedural changes), and verify the effectiveness of the preventive action. (Apply)

E. *Data analysis*

1. *Basic distribution types.* Define and distinguish between normal and binomial distributions and describe how their shapes (skewed and bimodal) can affect data interpretation. (Understand)

2. *Common and special cause variation.* Describe and distinguish between these types of variation. (Understand)

F. *Correlation and regression*

1. *Correlation.* Describe how correlation is used to identify relationships between variables. (Understand)

2. *Regression.* Describe how regression analysis is used to predict outcomes. (Understand)

G. *Hypothesis testing.* Define and distinguish between hypothesis terms (i.e., null and alternative, type I and type II error, p-value and power). (Understand)

V. *Improve and Control Phases* (14 Questions)

A. *Improvement techniques*

1. *Kaizen and kaizen blitz.* Define and distinguish between these two methods and describe how they can be used to make improvements to any process in an organization. (Understand)

2. *Plan-do-check-act (PDCA) cycle.* Define and distinguish between the steps in this process improvement tool. (Understand)

3. *Cost-benefit analysis.* Explain the importance of this analysis and how it is used in the improve phase. (Understand)

B. *Control tools and documentation*

1. *Control plan.* Describe the importance of a control plan for maintaining improvements. (Understand)

2. *Control charts.* Describe how $\bar{X} - R$ charts are used for monitoring and sustaining improved processes. (Understand)
3. *Document control.* Describe the importance of documenting changes to a process and communicating those changes to stakeholders. (Understand)
4. *Work instructions and standard operating procedures (SOPs).* Understand the purpose and use of work instructions and SOPs. (Understand)

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

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

Remember

Recall or recognize terms, definitions, facts, ideas, materials, patterns, sequences, methods, principles, etc.

Understand

Read and understand descriptions, communications, reports, tables, diagrams, directions, regulations, etc.

Apply

Know when and how to use ideas, procedures, methods, formulas, principles, theories, etc.

Analyze

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

Evaluate

Make judgments about the value of proposed ideas, solutions, etc., by comparing the proposal to specific criteria or standards.

Create

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

Appendix C
Control Limit Formulas

VARIABLES CHARTS

$\bar{x}$ and R chart:

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

$\bar{x}$ and s chart:

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

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

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

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

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

Median chart:

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

ATTRIBUTES CHARTS

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

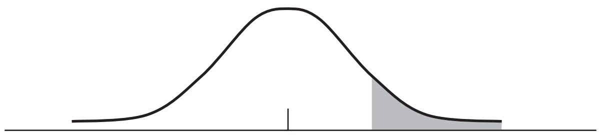
Appendix D

Constants for Control Charts

Subgroup size N	A_2	d_2	D_3	D_4	A_3	c_4	B_3	B_4	E_2	A2 for median charts	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 E

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

Continued

z	0.00	0.01	0.02	0.03	0.04
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
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

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
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

Continued

Continued

z	0.05	0.06	0.07	0.08	0.09
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 F

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

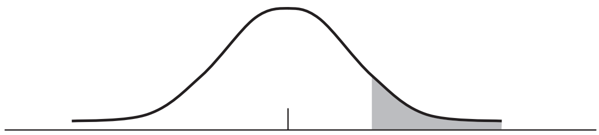
Continued

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 G

Values of the *t*-Distribution



Values of *t*-distribution

m	$t_{0.100}$	$t_{0.050}$	$t_{0.025}$	$t_{0.010}$	$t_{0.005}$	m
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

Continued

Continued

m	$t_{0.100}$	$t_{0.050}$	$t_{0.025}$	$t_{0.010}$	$t_{0.005}$	m
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
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 H
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

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

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

AQL—acceptable quality level

AQP—advanced quality planning

AQP—Association for Quality and Participation

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 varation

B2C—business to customer

BB—Black Belt

BBS—behavior based safety

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

BOB—best of the best

BoK—body of knowledge

BOM—bill of materials

BOS—business operating system

BPR—business process reengineering

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

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

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

CAR—corrective action recommendation

CAR—corrective action report

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 cards

CEO—chief executive officer

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

CFO—chief financial officer

CFR—USA Code of Federal Regulations

CGMP—current good manufacturing practice

CHA—ASQ Certified HACCP Auditor

CI—continual improvement

CIM—change-in-mean-effect

CIO—chief information officer

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

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

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

C_{pk}—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

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

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

CSM—customer–supplier model

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

CTC—critical to customer

CTQ—critical to quality

CTS—critical to satisfaction

CUSUM—cumulative sum control chart

CVEP—continuous value enhancement process

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

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

DOE—design of experiment(s)

DOT—United States Department of Transportation

DPM—defects per million units

DPMO—defects per million opportunities

DPO—defects per opportunity

DPPM—defective parts per million

DPU—defects per unit

DQC—data quality control

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

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

ECDF—empirical cumulative distribution function

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

EPSS—electronic performance support system

ER—engineering requirements

ERI—early return indicator

ERP—enterprise resource planning

ES—engineering specification

ESC—extreme service conditions

ESER—engineering sample evaluation report

ET—educational technology

ETA—event tree analysis

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

FAST—function analysis system technique

FCE—frequently committed errors

FEA—finite element analysis

FEA—front-end analysis

FIFO—first in, first out

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

FSL—flow synchronization leveling

FSS—full service supplier

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

GLM—general linear model

GLP—good laboratory practice

GM—General Motors Corporation

GMP—good manufacturing practice

GPC—gage performance curve

GQTS—global quality tracking system

GR&R—gage repeatability and reproducibility

GROW—goal, reality, options, way forward

GRPI—goals, roles, processes, interpersonal

GRR—gage repeatability and reproducibility

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

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

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

IMR—individuals and moving range

INT—interaction

IOBA—International Automotive Oversight Bureau

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

IRCA—International Register of Certified Auditors

IRR—internal rate of return

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)

ITU—International Telecommunication Union

JCAHO—Joint Commission on Accreditation of Healthcare Organizations

JDP—J. D. Power and Associates

JIS—Japan Industrial Standard

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

LCI—learner controlled instruction

LCL—lower control limit

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

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

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

MBNQA—Malcolm Baldrige National Quality Award

MBO—management by objectives

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

MPS—master production schedule

MQT—maintainability qualification test

MRA—mutual recognition arrangements

MRB—management review board

MRP—material requirements planning

MS—mean squares

MS (RES)—residual mean square

MSA—measurement systems analysis

MSB—mean square between treatments

MSD—maximum standard deviation

MSDS—Material Data Safety Sheet

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

MTTF—mean time to failure

MTTN—mean time to notification

MTTR—mean time to recover

MTTR—mean time to repair

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 Materiel 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

OBS—observation

OC—operating characteristic

OCAP—out-of-control action plan

OCC—operating characteristic curve

OCM—operating committee meeting

OCM—organizational change management

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

OJT—on-the-job training

OLE—overall labor effectiveness

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

PCD—process control document

PCR—product change request

PDA—personal data assistant

PDC—product development cycle

PDCA—plan–do–check–act

PDM—precedence diagram method

PDPC—process decision program chart

PDSA—plan–do–study–act

PE—professional engineer

PERT—program evaluation review technique

PFMEA—process 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

PMP—project management professional

PMS—planned maintenance system

PMTS—predetermined motion time system

PO—purchase order

PONC—price of nonconformance

P_p—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

P_{pk}—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

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

PSO—process sign-off

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 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

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)

RADHAZ—radio and radar radiation hazards

RAM—reliability, availability, and maintainability

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

RCA—root cause analysis

RCL—robustness checklist

RCM—reliability centered maintenance

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

RQL—rejectable quality level

RQMS—*Reliability and Quality Measurements for Telecommunications Systems*

RQT—reliability qualification test(ing)

RRA—residual risk assessment

RSM—repair station manual

RSM—response surface methodology

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

SB—service bulletin

SBP—strategic business plan

SC—significant characteristic

SCOT—strengths, challenge, opportunities, threats

SCP—service control point

SDCA—standardize–do–check–act

SDE—supplier development engineer

SDS—safety data sheet

SDWT—self-directed work team

SE—simultaneous engineering

SE—standard error

SET—senior executive team

SF—secondary float

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

SOP—standard operating procedure

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

SOQ—service-oriented architecture

SOR—sign-off report

SOW—statement 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

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

STOP—Safety Training Observation Program

STP—signaling transfer point

STS—synchronous transport signal

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

TOC—theory of constraints

TOPS—total operational performance system

TOU—terms of use

TPA—third-party audit

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

TS—technical specification

TSS—total sum of squares

TV—total variation

TVM—total value management

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

USL—upper specification limit

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—voice of the employee

VOP—voice of the process

VQD—visual quality document

VSAS—vehicle situational awareness system

VSM—value stream mapping

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

WQP—worldwide quality procedures

WQS—worldwide quality standards

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

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% 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.

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.

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% inspection and sampling. The relative amount of 100% inspection depends on the quality of submitted product. Continuous sampling plans usually require that each *t* period of 100% 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 5 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-benefit 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.

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.

detection—The likelihood the failure will be caught by the current controls before it gets to the customer (usually a scale of 1–5 or 1–10).

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, and (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% of the effects come from 20% 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 mechanism—Mechanism describing how the cause of the failure mode results in failure.

failure mode—Expressed as the inability to achieve the stated function.

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%—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

occurrence—The likelihood of a cause resulting in the occurrence of a failure mode. This may be based on historical data with other similar processes (usually a scale of 1–5 or 1–10).

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 can not 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% of the effects come from 20% 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 "100*p*" and "100*c*" 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*.

severity—The severity of the failure mode is based on the worst-case effect of the failure mode. Severity may range from safety concern (very high) to no effect (very low) (usually a scale of 1–5 or 1–10).

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 ($\pm 6\sigma$ 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% level of significance" or "5% 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, and (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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