# 1

# Introduction

## 1.1 Purpose of this Book

In this chapter, six sigma is defined as a method for problem solving. It is perhaps true that the main benefits of six sigma are: (1) the method slows people down when they solve problems, preventing them from prematurely jumping to poor recommendations that lose money; and (2) six sigma forces people to evaluate quantitatively and carefully their proposed recommendations. These evaluations can aid by encouraging adoption of project results and in the assignment of credit to participants. The main goal of this book is to encourage readers to increase their use of six sigma and its associated "sub-methods." Many of these sub-methods fall under the headings "statistical quality control" (SQC) and "design of experiments" (DOE), which, in turn, are associated with systems engineering and statistics.

"Experts" often complain that opportunities to use these methods are being missed. Former General Electric CEO Jack Welch, *e.g.*, wrote that six sigma is relevant in any type of organization from finance to manufacturing to healthcare. When there are "routine, relatively simple, repetitive tasks," six sigma can help improve performance, or if there are "large, complex projects," six sigma can help them go right the first time (Welch and Welch 2005). In this book, later chapters describe multiple true case studies in which students and others saved millions of dollars using six sigma methods in both types of situations.

Facilitating competent and wise application of the methods is also a goal. Incompetent application of methods can result in desirable outcomes. However, it is often easy to apply methods competently, *i.e.*, with an awareness of the intentions of methods' designers. Also, competent application generally increases the chance of achieving positive outcomes. Wisdom about how to use the methods can prevent over-use, which can occur when people apply methods that will not likely repay the associated investment. In some cases, the methods are incorrectly used as a substitute for rigorous thinking with subject-matter knowledge, or without properly consulting a subject-matter expert. These choices can cause the method applications to fail to return on the associated investments.

In Section 1.2, several terms are defined in relation to generic systems. These definitions emphasize the diversity of the possible application areas. People in all sectors of the world economy are applying the methods in this book and similar books. These sectors include health care, finance, education, and manufacturing. Next, in Section 1.3, problem-solving methods are defined. The definition of six sigma is then given in Section 1.4 in terms of a method, and a few specific principles and the related history are reviewed in Section 1.5. Finally, an overview of the entire book is presented, building on the associated definitions and concepts.

## 1.2 Systems and Key Input Variables

We define a "system" as an entity with "input variables" and "output variables." Also, we use "factors" synonymously with input variables and denote them $x_1,\ldots,x_m$. In our definition, all inputs must conceivably be directly controllable by some potential participant on a project team. We use responses synonymously with output variables and denote them $y_1,\ldots,y_q$. Figure 1.1 shows a generic system.

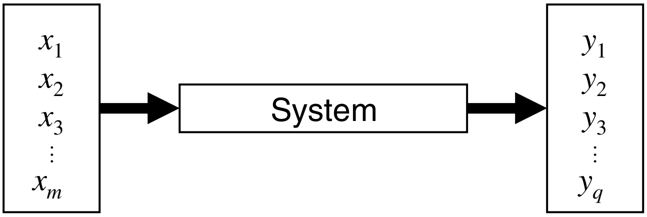


**Figure 1.1.** Diagram of a generic system

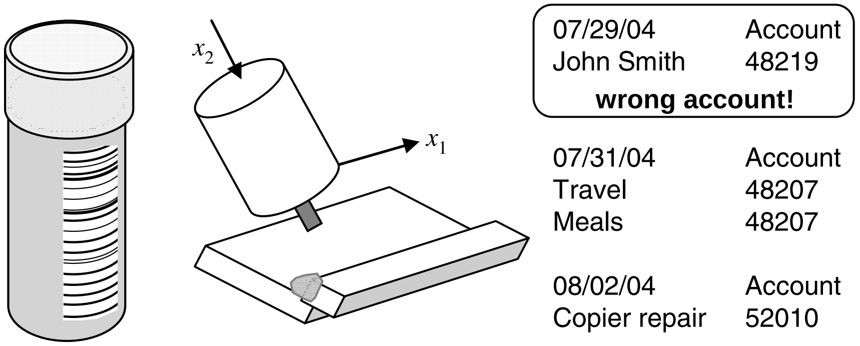
Assume that every system of interest is associated with at least one output variable of prime interest to you or your team in relation to the effects of input variable changes. We will call this variable a "**key output variable**" (KOV). Often, this will be the monetary contribution of the system to some entity's profits. Other KOV are variables that are believed to have a reasonably strong predictive relationship with at least one other already established KOV. For example, the most important KOV could be an average of other KOVs.

"**Key input variables**" (KIVs) are directly controllable by team members, *and* when they are changed, these changes will likely affect at least one key output variable. Note that some other books use the terms "key process input variables" (KPIVs) instead of key input variables (KIVs) and "key process output variables" (KPOVs) instead of key output variables (KOVs). We omit the word "process" because sometimes the system of interest is a product design and not a process. Therefore, the term "process" can be misleading.

A main purpose of these generic-seeming definitions is to emphasize the diversity of problems that the material in this book can address. Understandably, students usually do not expect to study material applicable to all of the following: (1) reducing errors in administering medications to hospital patients, (2) improving the welds generated by a robotic welding cell, (3) reducing the number of errors in accounting statements, (4) improving the taste of food, and (5) helping to increase the effectiveness of pharmaceutical medications. Yet, the methods in this book are currently being usefully applied in all these types of situations around the world.

Another purpose of the above definitions is to clarify this book's focus on choices about the settings of factors that we can control, *i.e.*, key input variables (KIVs). While it makes common sense to focus on controllable factors, students often have difficulty clarifying what variables they might reasonably be able to control directly in relation to a given system. Commonly, there is confusion between inputs and outputs because, in part, system inputs can be regarded as outputs. The opposite is generally not true.

The examples that follow further illustrate the diversity of relevant application systems and job descriptions. These examples also clarify the potential difficulty associated with identifying KIVs and KOVs. Figure 1.2 depicts objects associated with the examples, related to the medical, manufacturing, and accounting sectors of the economy.



(a) (b) (c)

**Figure 1.2.** **(a)** Pill box with bar code, **(b)** Weld torch, and **(c)** Accounting report

### Example 1.2.1 Bar-Coding Hospital System

**Question**: A hospital is trying to increase the quality of drug administration. To do this, it is considering providing patients with bar-coded wristbands and labeling unit dose medications with barcodes to make it easier to identify errors in patient and medication names, doses, routes, and times. Your team is charged with studying the effects of bar-coding by carefully watching 250 episodes in which drugs are given to patients without bar-coding and 250 episodes with bar-coding. Every time a drug is administered, you will check the amount, if any, of discrepancy between what was supposed to be given and what was given. List KIVs and KOVs and their units.

**Answer**: Possible KIVs and KOVs are listed in Table 1.1. Note also that the table is written implying that there is only one type of drug being administered. If there were a need to check the administration of multiple drugs, more output variables would be measured and documented. Then, it might be reasonable to assign a KOV as a weighted sum of the mistake amounts associated with different drugs.

In the above example, there was an effort made to define KOVs specifically associated with episodes and input combinations. In this case, it would also be standard to say that there is only one output variable "mistake amount" that is potentially influenced by bar-coding, the specific patient, and administration time. In general, it is desirable to be explicit so that it is clear what KOVs are and how to measure them. The purpose of the next example is to show that different people can see the same problem and identify essentially different systems. With more resources and more confidence with methods, people tend to consider simultaneously more inputs that can be adjusted.

**Table 1.1** Key input and output variables for the first bar-code investigation

| KIV | Description |
|---|---|
| $x_1$ | Bar-coding (Y or N) |

| KOV | Description |
|---|---|
| $y_1$ | Mistake amount patient #1 with $x_1$=N |
| $y_2$ | Mistake amount patient #2 with $x_1$=N |
| ⋮ | ⋮ |
| $y_{501}$ | Average amount with bar-coding |
| $y_{502}$ | Average amount without bar-coding |

### Example 1.2.2 Bar-Coding System Version 2

**Question**: Another hospital decides to launch a relatively thorough investigation of bar-coding, including evaluation of 1000 episodes in which drugs are given to patients. In addition to considering installing bar-coding, investigators simultaneously consider (1) the use of sustained-release medications that can be administered at wider intervals, (2) assigning fewer patients to each nurse, (3) setting a limit on how much time nurses can spend chatting with patients, and (4) shortening the nurses shift hours. They plan on testing 10 combinations of these inputs multiple times each. In addition to correct dosage administration, they also want to evaluate the effects of changes on the job satisfaction of the 15 current nurses. Patient satisfaction is a possible concern, but no one on the team really believes that bar-coding affects it. Define and list KIVs and KOVs and their units.

**Answer**: Possible KIVs and KOVs are listed in Table 1.2. Patient satisfaction ratings are not included as KOVs. This follows despite the fact that all involved believe they are important. However, according to the definition here, key output variables must be likely to be affected by changes in the inputs being considered or believed to have a strong predictive relationship with other KOVs. Also, note that the team cannot control exactly how much time nurses spend with patients. However, the team could write a policy such that nurses could tell patients, "I cannot spend more than *X* minutes with you according to policy."

Note in the above example that average differences in output averages conditioned on changes in inputs could be included in the KOV list. Often, developing statistical evidence for the existence of these differences is the main goal of an investigation. The list of possible KOVs is rarely exhaustive, in the sense that more could almost always be added. Yet, if an output is mentioned directly or indirectly as important by the customer, subject matter expert, or team member, it should be included in the list.

The next example illustrates a case in which an input is also an output. Generally, inputs are directly controllable, and at least one output under consideration is only indirectly controllable through adjustments of input variable setting selections. Admittedly, the distinctions between inputs and outputs in virtual or simulated world can be blurry. Yet, in this book we focus on the assumption that inputs are controllable, and outputs, with few exceptions, are not. The next example also constitutes a relatively "traditional" system, in the sense that the methods in this book have historically not been primarily associated with projects in the service sector.

**Table 1.2** The list of inputs and outputs for the more thorough investigation

| KIV | Description |
|---|---|
| $x_1$ | Bar-coding (Y or N) |
| $x_2$ | Spacing on tray (millimeters) |
| $x_3$ | Number of patients (#) |
| $x_4$ | Nurse-patient time[a] (minutes) |
| $x_5$ | Shift length (hours) |

| KOV | Description |
|---|---|
| $y_1$ | Mistake amount patient-combo. #1 (cc) |
| $y_2$ | Mistake amount patient-combo. #2 (cc) |
| $\vdots$ | $\vdots$ |
| $y_{1000}$ | Mistake amount patient-combo. #1000 (cc) |
| $y_{1002}$ | Nurse #1 rating for input combo. #1 |
| $\vdots$ | $\vdots$ |
| $y_{1150}$ | Nurse #15 rating for input combo. #20 |

[a] Stated policy is less than $X$

### Example 1.2.3 Robotic Welding System

**Question**: The shape of welds strongly relates to profits, in part because operators commonly spend time fixing or reworking welds with unacceptable shapes. Your team is investigating robot settings that likely affect weld shape, including weld speed, voltage, wire feed speed, time in acid bath, weld torch contact tip-to-work distance, and the current frequency. Define and list KIVs and KOVs and their units.

**Answer**: Possible KIVs and KOVs are listed in Table 1.3. Weld speed can be precisely controlled and likely affects bead shape and therefore profits. Yet, since the number of parts made per minute likely relates to revenues per minute (*i.e.*, throughput), it is also a KOV.

The final example system considered here relates to annoying accounting mistakes that many of us experience on the job. Applying systems thinking to monitor and improve accounting practices is of increasing interest in industry.

### Example 1.2.4 Accounting System

**Question**: A manager has commissioned a team to reduce the number of mistakes in the reports generated by all company accounting departments. The manager decides to experiment with both new software and a changed policy to make supervisors directly responsible for mistakes in expense reports entered into the system. It is believed that the team has sufficient resources to check carefully 500 reports generated over two weeks in one "guinea pig" divisional accounting department where the new software and policies will be tested.

**Table 1.3** Key input and output variables for the welding process design problem

| KIV | Description |
|---|---|
| $x_1$ | Weld speed (minutes/weld) |
| $x_2$ | Wire feed speed (meters/minute) |
| $x_3$ | Voltage (Volts) |
| $x_4$ | Acid bath time (min) |
| $x_5$ | Tip distance (mm) |
| $x_6$ | Frequency (Hz) |

| KOV | Description |
|---|---|
| $y_1$ | Convexity for weld #1 |
| $y_2$ | Convexity for weld #2 |
| $\vdots$ | $\vdots$ |
| $y_{501}$ | % Acceptable for input combo. #1 |
| $\vdots$ | $\vdots$ |
| $y_{550}$ | Weld speed (minutes/weld) |

**Answer**: Possible KIVs and KOVs are listed in Table 1.4.

**Table 1.4** Key input and output variables for the accounting systems design problem

| KIV | Description |
|---|---|
| $x_1$ | New software (Y or N) |
| $x_2$ | Change(Y or N) |

| KOV | Description |
|---|---|
| $y_1$ | Number mistakes report #1 |
| $y_2$ | Number mistakes report #2 |
| $\vdots$ | $\vdots$ |
| $y_{501}$ | Average number mistakes $x_1$=Y, $x_2$=Y |
| $y_{502}$ | Average number mistakes $x_1$=N, $x_2$=Y |
| $y_{503}$ | Average number mistakes $x_1$=Y, $x_2$=N |
| $y_{504}$ | Average number mistakes $x_1$=N, $x_2$=N |

## 1.3 Problem-solving Methods

The definition of systems is so broad that all knowledge workers could say that a large part of their job involves choosing input variable settings for systems, *e.g.*, in accounting, education, health care, or manufacturing. This book focuses on activities that people engage in to educate themselves in order to select key input variable settings. Their goals are expressable in terms of achieving more desirable key output variable (KOV) values. It is standard to refer to activities that result in recommended inputs and other related knowledge as "**problem-solving methods**."

Imagine that you had the ability to command a "**system genie**" with specific types of powers. The system genie would appear and provide ideal input settings for any system of interest and answer all related questions. Figure 1.3 illustrates a genie based problem-solving method. Note that, even with a trustworthy genie, steps 3 and 4 probably would be of interest. This follows because people are generally interested in more than just the recommended settings. They would also desire predictions of the impacts on all KOVs as a result of changing to these settings and an educated discussion about alternatives.

In some sense, the purpose of this book is to help you and your team efficiently transform yourselves into genies for the specific systems of interest to you. Unfortunately, the transformation involves more complicated problem-solving methods than simply asking an existing system genie as implied by Figure 1.3. The methods in this book involve potentially all of the following: collecting data, performing analysis and formal optimization tasks, and using human judgement and subject-matter knowledge.

*Step 1*: Summon genie.

*Step 2*: Ask genie what settings to use for $x_1,\ldots,x_m$.

*Step 3*: Ask genie how KOVs will be affected by changing current inputs to these settings.

*Step 4*: Discuss with genie the level of confidence about predicted outputs and other possible options for inputs.

**Figure 1.3.** System genie-based problem-solving method

Some readers, such as researchers in statistics and operations research, will be interested in designing new problem-solving methods. With them in mind, the term "**improvement system**" is defined as a problem-solving method. The purpose of this definition is to emphasize that methods can themselves be designed and improved. Yet methods differ from other systems, in that benefits from them are derived largely indirectly through the inputting of derived factor settings into other systems.

### 1.3.1 What Is "Six Sigma"?

The definition of the phrase "**six sigma**" is somewhat obscure. People and organizations that have played key roles in encouraging others to use the phrase include the authors Harry and Schroeder (1999), Pande *et al.* (2000), and the

American Society of Quality. These groups have clarified that "six sigma" pertains to the attainment of desirable situations in which the fraction of unacceptable products produced by a system is less than 3.4 per million opportunities (PMO). In Part I of this book, the exact derivation of this number will be explained. The main point here is that a key output characteristic (KOV) is often the fraction of manufactured units that fail to perform up to expectations.

Here, the definition of six sigma is built on the one offered in Linderman *et al.* (2003, p. 195). Writing in the prestigious *Journal of Operations Management*, those authors emphasized the need for a common definition of six sigma and proposed a definition paraphrased below:

> Six sigma is an organized and systematic problem-solving method for strategic system improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates and/or improvements in key output variables.

The authors further described that while "the name Six Sigma suggests a goal" of less than 3.4 unacceptable units PMO, they purposely did not include this principle in the definition. This followed because six sigma "advocates establishing goals based on customer requirements." It is likely true that sufficient consensus exists to warrant the following additional specificity about the six sigma method:

The six sigma method for completed projects includes as its phases either Define, Measure, Analyze, Improve, and Control (DMAIC) for system improvement or Define, Measure, Analyze, Design, and Verify (DMADV) for new system development.

Note that some authors use the term Design For Six Sigma (DFSS) to refer to the application of six sigma to design new systems and emphasize the differences compared with system improvement activities.

Further, it is also probably true that sufficient consensus exists to include in the definition of six sigma the following two principles:

> **Principle 1**: The six sigma method only fully commences a project after establishing adequate monetary justification.
>
> **Principle 2**: Practitioners applying six sigma can and should benefit from applying statistical methods without the aid of statistical experts.

The above definition of six sigma is not universally accepted. However, examining it probably does lead to appropriate inferences about the nature of six sigma and of this book. First, six sigma relates to combining statistical methods and the scientific method to improve systems. Second, six sigma is fairly dogmatic in relation to the words associated with a formalized method to solve problems. Third, six sigma is very much about saving money and financial discipline. Fourth, there is an emphasis associated with six sigma on training people to use statistical tools who will never be experts and may not come into contact with experts. Finally, six sigma focuses on the relatively narrow set of issues associated with *technical* methods for improving *quantitative* measures of identified subsystems in relatively short periods of time. Many "softer" and philosophical issues about how to motivate people, inspire creativity, invoke the principles of design, or focus on the ideal endstate of systems are not addressed.

**Example 1.3.1 Management Fad?**

**Question**: What aspects of six sigma suggest that it might not be another passing management fad?

**Answer**: Admittedly, six sigma does share the characteristic of many fads in that its associated methods and principles do not derive from any clear, rigorous foundation or mathematical axioms. Properties of six sigma that suggest that it might be relevant for a long time include: (1) the method is relatively specific and therefore easy to implement, and (2) six sigma incorporates the principle of budget justification for each project. Therefore, participants appreciate its lack of ambiguity, and management appreciates the emphasis on the bottom line.

Associated with six sigma is a training and certification process. Principle 2 above implies that the goal of this process is not to create statistical experts. Other properties associated with six sigma training are:

1. Instruction is "case-based" such that all people being trained are directly applying what they are learning.

2. Multiple statistics, marketing, and optimization "component methods" are taught in the context of an improvement or "problem-solving" method involving five ordered "**activities.**" These activities are either "Define" (D), "Measure" (M), "Analyze" (A), "Improve" (I), and "Control" (C) in that order (DMAIC) or "Define" (D), "Measure" (M), "Analyze" (A), "Design" (D), "Verify" (V) (DMADV).

3. An application process is employed in which people apply for training and/or projects based on the expected **profit** or return on investment from the project, and the profit is measured after the improvement system completes.

4. Training certification levels are specified as "**Green Belt**" (perhaps the majority of employees), "**Black Belt**" (project leaders and/or method experts), and "**Master Black Belt**" (training experts).

Many companies have their own certification process. In addition, the American Society of Quality (ASQ) offers the Black Belt certification. Current requirements include completed projects with affidavits and an acceptable score on a written exam.

## 1.4 History of "Quality" and Six Sigma

In this section, we briefly review the broader history of management, applied statistics, and the six sigma movement. The definition of "**quality**" is as obscure as the definition of six sigma. Quality is often defined imprecisely in textbooks in terms of a subjectively assessed performance level (P) of the unit in question and the expections (E) that customers have for that unit. A rough formula for quality (Q) is:

$$\mathrm{Q} = \frac{P}{E} \tag{1.1}$$

Often, quality is considered in relation to thousands of manufactured parts, and a key issue is why some fail to perform up to expectation and others succeed.

It is probably more helpful to think of "quality" as a catch-word associated with management and engineering decision-making using data and methods from applied statistics. Instead of relying solely on "seat-of-the-pants" choices and the opinions of experts, people influenced by quality movements gather data and apply more disciplined methods.

### 1.4.1 History of Management and Quality

The following history is intended to establish a context for the current quality and six sigma movements. This explanation of the history of management and quality is influenced by Womack and Jones (1996) related to so-called "Lean Thinking" and "**value stream mapping**" and other terms in the Toyota production system.

In the renaissance era in Europe, fine objects including clocks and guns were developed using "**craft**" production. In craft production, a single skilled individual is responsible for designing, building, selling, and servicing each item. Often, a craftperson's skills are certified and maintained by organizations called "**guilds**" and professional societies.

During the 1600s and 1700s, an increasing number of goods and services were produced by machines, particularly in agriculture. Selected events and the people responsible are listed in Figure 1.4.

It was not until the early 1900s that a coherent alternative to craft production of fine objects reached maturity. In 1914, Ford developed "Model T" cars using an "assembly line" in which many unskilled workers each provided only a small contribution to the manufacturing process. The term "**mass production**" refers to a set of management policies inspired by assembly lines. Ford used assembly lines to make large numbers of nearly identical cars. His company produced component parts that were "**interchangeable**" to an impressive degree. A car part could be taken from one car, put on another car, and still yield acceptable performance.

As the name would imply, another trait of mass production plants is that they turn out units in large batches. For example, one plant might make 1000 parts of one type using a press and then change or "set up" new dies to make 1000 parts of a different type. This approach has the benefit of avoiding the costs associated with large numbers of change-overs.

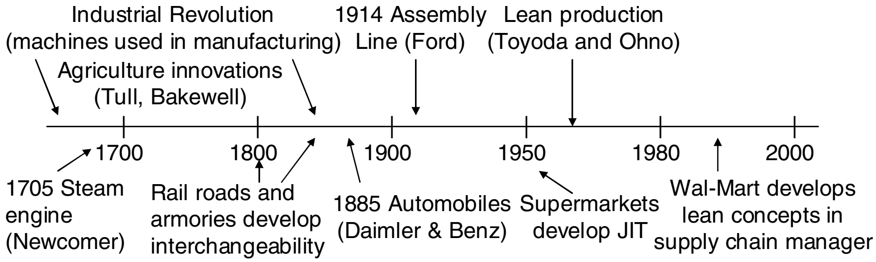


**Figure 1.4.** Timeline of selected management methods (includes Toyoda at Toyota)

Significant accountability for product performance was lost in mass production compared with craft production. This follows because the people producing the product each saw only a very small part of its creation. Yet, benefits of mass production included permitting a huge diversity of untrained people to contribute in a coordinated manner to production. This in turn permitted impressive numbers of units to be produced per hour. It is also important to note that both craft and mass production continue to this day and could conceivably constitute profitable modes of production for certain products and services.

Mass production concepts contributed to intense specialization in other industrial sectors besides manufacturing and other areas of the corporation besides production. Many companies divided into departments of marketing, design engineering, process engineering, production, service, purchasing, accounting, and quality. In each of these departments people provide only a small contribution to the sale of each unit or service. The need to counteract the negative effects of specialization at an organizational level has led to a quality movement called "**concurrent engineering**" in which people from multiple disciplines share information. The interaction among production, design engineering, and marketing is considered particularly important, because design engineering often largely determines the final success of the product. Therefore, design engineers need input about customer needs from marketing and production realities from production.

The Toyota production system invented in part by Toyoda and Ohno, also called "lean production" and "just-in-time" (JIT), built in part upon innovations in U.S. supermarkets. The multiple further innovations that Toyota developed in turn influenced many areas of management and quality-related thinking including increased outsourcing in supply-chain management. In the widely read book *The Machine that Changed the World*, Womack *et al.* (1991) explained how Toyota, using its management approach, was able to transform quickly a failing GM plant to produce at least as many units per day with roughly one half the personnel operating expense and with greatly improved quality by almost any measure. This further fueled the thirst in the U.S. to learn from all things Japanese.

JIT creates accountability by having workers follow products through multiple operations in "U"-shaped cells (*i.e.*, machines laid out in the shape of a "U") and by implementing several policies that greatly reduce work-in-process (WIP) inventory. To the maximum extent possible, units are made in **batches of size one**, *i.e.*, creating a single unit of one type and then switching over to a single of another type of unit and so on. This approach requires frequent equipment set-ups. To compensate, the workers put much effort into reducing set-up costs, including the time required for set-ups. Previously, many enterprises had never put effort into reducing set-ups because they did not fully appreciate the importance.

Also, the total inventory at each stage in the process is generally regulated using kanban cards. When the cards for a station are all used up, the process shuts down the upstream station, which can result in shutting down entire supply chains. The benefit is increased attention to the problems causing stoppage and (hopefully) permanent resolution. Finally, lean production generally includes an extensive debugging process; when a plant starts up with several stoppages, many people focus on and eliminate the problems. With small batch sizes, "U" shaped cells, and reduced WIP, process problems are quickly discovered before nonconforming units accumulate.

### Example 1.4.1 Lean Production of Paper Airplanes

**Question**: Assume that you and another person are tasked with making a large number of paper airplanes. Each unit requires three operations: (1) marking, (2) cutting, and (3) folding. Describe the mass and lean ways to deploy your resources. Which might generate airplanes with higher quality?

**Answer**: A mass production method would be to have one person doing all the marking and cutting and the other person doing all the folding. The lean way would have both people doing marking, cutting, and folding to make complete airplanes. The lean way would probably produce higher quality because, during folding, people might detect issues in marking and cutting. That information would be used the next time to improve marking and cutting with no possible loss associated with communication. (Mass production might produce units more quickly, however.)

In addition to studying Toyota's lean production, observers compare many types of business practices at European, Japanese, and U.S. companies. One finding at specific companies related to the timing of design changes at automotive companies. In the automotive industry, "Job 1" is the time when the first production car roles off the line. A picture emerged, shown in Figure 1.5.

Figure 1.5 implies that at certain automotive companies in Japan, much more effort was spent investigating possible design changes long before Job 1. At certain U.S. car companies, much more of the effort was devoted after Job 1 reacting to problems experience by customers. This occurred for a variety of reasons. Certain Japanese companies made an effort to institutionalize a forward-looking design process with "**design freezes**" that were taken seriously by all involved. Also, engineers at these specific companies in Japan were applying design of experiments (DOE) and other formalized problem-solving methods more frequently than their U.S. counterparts. These techniques permit the thorough exploration of large numbers of alternatives long before Job 1, giving people more confidence in the design decisions.

Even today, in probably all automotive companies around the world, many engineers are in "**reactive mode**," constantly responding to unforeseen problems. The term "**fire-fighting**" refers to reacting to these unexpected occurrences. The need to fire-fight is, to a large extent, unavoidable. Yet the cost per design change plot in Figure 1.5 is meant to emphasize the importance of avoiding problems rather than fire-fighting. Costs increase because more and more tooling and other coordination efforts are committed based on the current design as time progresses. Formal techniques taught in this book can play a useful role in avoiding or reducing the number of changes needed after Job 1, and achieving benefits including reduced tooling and coordination costs and decreased need to fire-fight.

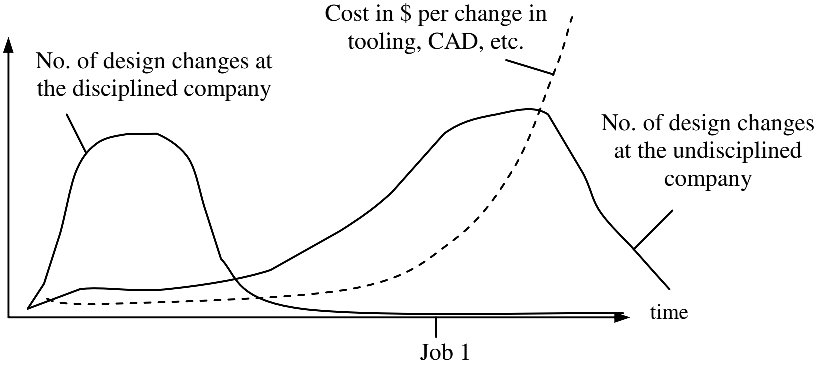


**Figure 1.5.** Formal planning can reduce costs and increase agility

Another development in the history of quality is "**miniaturization**". Many manufactured items in the early 2000s have literally millions of critical characteristics, all of which must conform to specifications in order for the units to yield acceptable performance. The phrase "**mass customization**" refers to efforts to tailor thousands of items such as cars or hamburgers to specific customers' needs. Mass customization, like miniaturization, plays an important role in the modern work environment. Ford's motto was, "You can have any color car as long as it is black." In the era of global competition, customers more than ever demand units made to their exact specifications. Therefore, in modern production, customers introduce additional variation to the variation created by the production process.

### Example 1.4.2 Freezing Designs

**Question**: With respect to manufacturing, how can freezing designs help quality?

**Answer**: Often the quality problem is associated with only a small fraction of units that are not performing as expected. Therefore, the problem must relate to something different that happened to those units, *i.e.*, some variation in the production system. Historically, engineers "tweaking" designs has proved to be a major source of variation and thus a cause of quality problems.

### 1.4.2 History of Documentation and Quality

The growing role of documentation of standard operating procedures (SOPs) also relates to management history. The International Standards Organization (ISO) developed in Europe but was influenced in the second half of the twentieth century by U.S. military standards. The goals of ISO included the development of standard ways that businesses across the world could use to document their practices. ISO standards for documenting business practices, including "ISO 9000: 1994" and "ISO 9000: 2000" document series aimed to reduce variation in production.

ISO 9000: 1994 emphasized addressing 20 points and the basic guideline "Do what you say and say what you do." In other words, much emphasis was placed on whether or not the company actually used its documented policies, rather than on the content of those policies. ISO 9000:2000 added more requirements for generating models to support and improve business subsystems. Companies being accredited pay credentialed auditors to check that they are in compliance at regular intervals. The results include operating manuals at many accredited institutions that reflect truthfully, in some detail, how the business is being run.

Perceived benefits of ISO accreditation include: (1) reducing quality problems of all types through standardization of practices, and (2) facilitating training when employees switch jobs or leave organizations. Standardization can help by forcing people to learn from each other and to agree on a single approach for performing a certain task. ISO documentation also discourages engineers from constantly tinkering with the design or process.

Another perceived benefit of ISO documentation relates to the continuing trend of companies outsourcing work formerly done in-house. This trend was also influenced by Toyota. In the 1980s researchers noticed that Toyota trusted its suppliers with much more of the design work than U.S. car makers did, and saved a great deal of money as a result. Similar apparent successes with these methods followed at Chrysler and elsewhere, which further encouraged original equipment manufacturers (OEMs) to increase outsourcing. The OEMs have now become relatively dependent on their "**supply chain**" for quality and need some way to assure intelligent business practices are being used by suppliers.

While ISO and other documentation and standardization can eliminate sources of variation, the associated "**red tape**" and other restrictive company policies can also, of course, sometimes stifle creativity and cost money. Some authors have responded by urging careful selection of employees and a "culture of discipline" (Collins 2001). Collins suggests that extensive documentation can, in some cases, be unnecessary because it is only helpful in the case of a few problem employees who might not fit into an organization. He bases his recommendations on a study of policies at exceptional and average companies based on stock performance.

### 1.4.3 History of Statistics and Quality

Corporations routinely apply statistical methods, partly in response to accountability issues, as well as due to the large volume of items produced, miniaturization, and mass customization. An overview of selected statistical methods is provided in Figure 1.6. The origin of these methods dates back at least to the invention of calculus in the 1700s. Least squares regression estimation was one of the first optimization problems addressed in the calculus/optimization literature. In the early 1900s, statistical methods played a major role in improving agricultural production in the U.K. and the U.S. These developments also led to new methods, including fractional factorials and analysis of variance (ANOVA) developed by Sir Ronald Fisher (Fisher 1925).

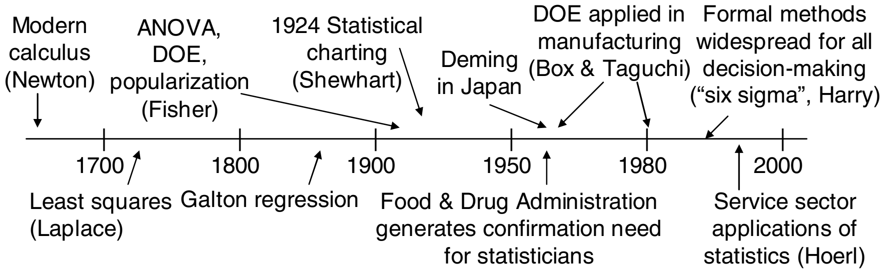


**Figure 1.6.** Timeline of selected statistical methods

The realities of mass production led W. Shewhart working in 1924 at Bell Laboratories to propose statistical process control (SPC) methods (see www.research.att.com/areas/stat/info/history.html). The specific "**X-Bar and R**" charts he developed are also called "Shewhart" charts. These methods discourage process tinkering unless statistical evidence of unusual occurrences accrues. Shewhart also clarified the common and harmful role that variation plays in manufacturing, causing a small fraction of unit characteristics to wander outside their specification limits. The implementation of Shewhart charts also exposed many unskilled workers to statistical methods.

In the 1950s, the U.S. Food and Drug Administration required companies to hire "statisticians" to verify the safety of food and drugs. Many universities developed statistics departments largely in response to this demand for statisticians. Perhaps as a result of this history, many laypeople tend to associate statistical methods with proving claims to regulatory bodies.

At the same time, there is a long history of active uses of statistical methods to influence decision-making unrelated to regulatory agencies. For example, many kinds of statistical methods were used actively in formal optimization and the science of "**operations research**" for the military during and after World War II. During the war Danzig and Wood used linear programming—developed for crop optimization—in deploying convoys. Monte Carlo simulation methods were also used for a wide variety of purposes ranging from evaluating factory flows to gaming nuclear attacks and predicting fallout spread.

George Box, Genichi Taguchi, and many others developed design of experiments (DOE) methods and new roles for statisticians in the popular consciousness besides verification. These methods were intended to be used early in the process of designing products and services. In the modern workplace, people in all departments, including marketing, design engineering, purchasing, and production, routinely use applied statistics methods. The phrases "business statistics" and "engineering statistics" have come into use partially to differentiate statistical methods useful for helping to improve profits from methods useful for such purposes as verifying the safety of foods and drugs (“standard statistics”), or the assessment of threats from environmental contaminants.

Edward Deming is credited with playing a major role in developing so-called “**Total Quality Management**” (TQM). Total quality management emphasized the ideas of Shewhart and the role of data in management decision-making. TQM continues to increase awareness in industry of the value of quality techniques including design of experiments (DOE) and statistical process control (SPC). It has, however, been criticized for leaving workers with only a vague understanding of the exact circumstances under which the methods should be applied and of the bottom line impacts.

Because Deming’s ideas were probably taken more seriously in Japan for much of his career, TQM has been associated with technology transfer from the U.S. to Japan and back to the U.S. and the rest of the world. Yet in general, TQM has little to do with Toyota’s lean production, which was also technology transfer from Japan to the rest of the world. Some credible evidence has been presented indicating that TQM programs around the world have resulted in increased profits and stock prices (Kaynak 2003). However, a perception developed in the 1980s and 1990s that these programs were associated with “anti-business attitudes” and “muddled thinking.”

This occurred in part because some of the TQM practices such as “quality circles” have been perceived as time-consuming and slow to pay off. Furthermore, the perception persists to this day that the roles of statistical methods and their use in TQM are unclear enough to require the assistance of a statistical expert in order to gain a positive outcome. Also, Deming placed a major emphasis on his “14 points,” which included #8, “Drive out fear” from the workplace. Some managers and employees honestly feel that some fear is helpful. It was against this backdrop that six sigma developed.

### Example 1.4.3 Japanese Technology

**Question**: Drawing on information from this chapter and other sources, briefly describe three quality technologies transferred from Japan to the rest of the world.

**Answer**: First, lean production was developed at Toyota which has its headquarters in Japan. Lean production includes two properties, among others: inventory at each machine center is limited using kanban cards, and U-shaped cells are used in which workers follow parts for many operations which instills worker accountability. However, lean production might or might not relate to the best way to run a specific operation. Second, quality circles constitute a specific format for sharing quality-related information and ideas. Third, a Japanese consultant named Genechi Taguchi developed some specific DOE methods with some advantages that will be discussed briefly in Part II of this book. He also emphasized the idea of using formal methods to help bring awareness of production problems earlier in the design process. He argued that this can reduce the need for expensive design changes after Job 1.

### 1.4.4 The Six Sigma Movement

The six sigma movement began in 1979 at Motorola when an executive declared that "the real problem [is]…quality stinks." With millions of critical characteristics per integrated circuit unit, the percentage of acceptable units produced was low enough that these quality problems obviously affected the company's profits.

In the early 1980s, Motorola developed methods for problem-solving that combined formal techniques, particularly relating to measurement, to achieve measurable savings in the millions of dollars. In the mid-1980s, Motorola spun off a consulting and training company called the "Six Sigma Academy" (SSA). SSA president Mikel Harry led that company in providing innovative case-based instruction, "black belt" accreditations, and consulting. In 1992, Allied Signal based its companywide instruction on Six Sigma Academy techniques and began to create job positions in line with Six Sigma training levels. Several other companies soon adopted Six Sigma Academy training methods, including Texas Instruments and ABB.

Also during the mid-1990s, multiple formal methodologies to structure product and process improvement were published. These methodologies have included Total Quality Development (*e.g.*, see Clausing 1994), Taguchi Methods (*e.g.*, see Taguchi 1993), the decision analysis-based framework (*e.g.*, Hazelrigg 1996), and the so-called "six sigma" methodology (Harry and Schroeder 1999). All these published methods developments aim to allow people involved with system improvement to use the methods to structure their activities even if they do not fully understand the motivations behind them.

In 1995, General Electric (GE) contracted with the "Six Sigma Academy" for help in improving its training program. This was of particular importance for popularizing six sigma because GE is one of the world's most admired companies. The Chief Executive Officer, Jack Welch, forced employees at all levels to participate in six sigma training and problem-solving approaches. GE's approach was to select carefully employees for Black Belt instruction, drawing from employees believed to be future leaders. One benefit of this approach was that employees at all ranks associated six sigma with "winners" and financial success. In 1999, GE began to compete with Six Sigma Academy by offering six sigma training to suppliers and others. In 2000, the American Society of Quality initiated its "black belt" accreditation, requiring a classroom exam and signed affidavits that six sigma projects had been successfully completed.

Montgomery (2001) and Hahn *et al.* (1999) have commented that six sigma training has become more popular than other training in part because it ties standard statistical techniques such as control charts to outcomes measured in monetary and/or physical terms. No doubt the popularity of six sigma training also derives in part from the fact that it teaches an assemblage of techniques already taught at universities in classes on applied statistics, such as gauge repeatability and reproducibility (R&R), statistical process control (SPC), design of experiments (DOE), failure modes and effects analysis (FMEA), and cause and effect matrices (C&E).

All of the component techniques such as SPC and DOE are discussed in Pande *et al.* (2000) and defined here. The techniques are utilized and placed in the context of a methodology with larger scope, *i.e.*, the gathering of information from engineers and customers and the use of this information to optimize system design and make informed decisions about the inspection techniques used during system operation.

Pande *et al.* (2000) contributed probably the most complete and explicit version of the six sigma methods in the public domain. Yet even their version of the methodology (perhaps wisely) leaves implementers considerable latitude to tailor approaches to applications and to their own tastes. This lack of standardization of methodologies explains, at least in part, why the American Society for Quality still has only recently introduced a six sigma "black belt" certification process. An exception is a proprietary process at General Electric that "green belt" level practitioners are certified to use competently.

**Example 1.4.4 Lean Sigma**

**Question**: How do six sigma and lean production relate?

**Answer**: Six sigma is a generic method for improving systems or designing new products, while lean manufacturing has a greater emphasis on the best structure, in Toyota's view, of a production system. Therefore, six sigma focuses more on *how* to implement improvements or new designs using statistics and optimization methods in a structured manner. Lean manufacturing focuses on *what* form to be implemented for production systems, including specific high-level decisions relating to inventory management, purchasing, and scheduling of operations, with the goal of emulating the Toyota Production System. That being said, there are "kaizen events" and "value stream mapping" activities in lean production. Still, the overlap is small enough that many companies have combined six sigma and lean manufacturing efforts under the heading "lean sigma."

## 1.5 The Culture of Discipline

The purpose of this section is to summarize the practical reasons for considering using any formal SQC or DOE techniques rather than trial and error. These reasons can be helpful for motivating engineers and scientists to use these methods, and for overcoming human tendencies to avoid activities requiring intellectual discipline. This motivation might help to build something like the data-driven "culture of discipline" identified by Collins (2001).

The primary reason for formality in decision-making is the common need for extremely high quality levels. This follows from growing international competition in all sectors of the economy. Also, miniaturization and mass customization can make problems hard to comprehend. Often, for the product to have a reasonable chance of meeting customer expectations, the probability that each quality characteristic will satisfy expectations (the "yield") must be greater than 99.99%. Workers in organizations often discover that competitor companies are using formal techniques to achieve the needed quality levels with these tough demands.

Why might formal methods be more likely than trial and error to achieve these extreme quality levels? Here, we will use the phrase "One-Factor-at-a-Time" (OFAT) to refer to trial-and-error experimentation, following the discussion in Czitrom (1999). Intuitively, one performs experimentation because one is uncertain which alternatives will give desirable system outputs. Assume that each alternative tested thoroughly offers a roughly equal probability of achieving process goals. Then the method that can effectively thoroughly test more alternatives is more likely to result in better outcomes.

Formal methods (1) spread tests out inside the region of interest where good solutions are expected to be and (2) provide a thorough check of whether changes help. For example, by using interpolation models, *e.g.*, linear regressions or neural nets, one can effectively thoroughly test all the solutions throughout the region spanned by these experimental runs.

OFAT procedures have the advantages of being relatively simple and permitting opportunistic decision-making. Yet, for a given number of experimental runs, these procedures effectively test far fewer solutions, as indicated by the regions in Figure 1.7 below. Imagine the dashed lines indicate contours of yield as a function of two control factors, $x_1$ and $x_2$. The chance that the OFAT search area contains the high yield required to be competitive is far less than the formal method search area.

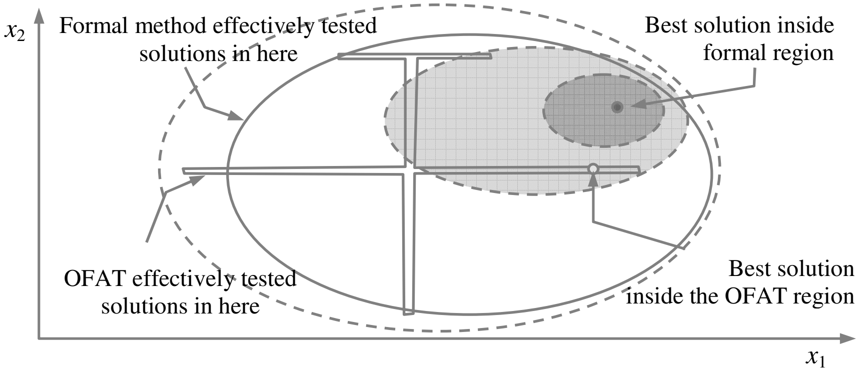


**Figure 1.7.** Formal procedures search much larger spaces for comparable costs

A good engineer can design products that work well under ideal circumstances. It is far more difficult, however, to design a product that works well for a range of conditions, *i.e.*, noise factor settings as defined originally by Taguchi. This reason is effectively a restatement of the first reason because it is intuitively clear that it is noise factor variation that causes the yields to be less than 100.00000%. Something must be changing in the process and/or the environment. Therefore, the designers' challenge, clarified by Taguchi, is to design a product that gives performance robust to noise factor variation. To do this, the experimenter must consider an expanded list of factors including both control and noise factors. This tends to favor formal methods because typically the marginal cost of adding factors to the experimental plan in the context of formal methods (while achieving comparable method performance levels, *e.g.*, probabilities of successful identification or prediction errors) is much less than for OFAT.

Often there is a financial imperative to “freeze” an engineering design early in the design process. Then it is important that this locked in design be good enough, including robust enough, such that stakeholders do not feel the need to change the design later in the process. Formal methods can help to establish a disciplined product and/or process development timeline to deliver high quality designs early.

The financial problem with the wait-and-see attitude based on tinkering and not upfront formal experimentation is that the costs of changing the design grow exponentially with time. This follows because design changes early in the process mainly cost the time of a small number of engineers. Changes later in the process cause the need for more changes, with many of these late-in-the-process changes requiring expensive retooling and coordination costs. Also, as changes cause the need for more changes, the product development time can increase dramatically, reducing the company’s “agility” in the marketplace.

### Example 1.5.1 Convincing Management

**Question**: What types of evidence are most likely to convince management to invest in training and usage of formal SQC and DOE techniques?

**Answer**: Specific evidence that competitor companies are saving money is most likely to make management excited about formal techniques. Also, many people at all levels are impressed by success stories. The theory that discipline might substitute for red tape might also be compelling.

## 1.6 Real Success Stories

Often students and other people are most encouraged to use a product or method by stories in which people like them had positive experiences. This book contains four complete case studies in which the author or actual students at The Ohio State University participated on teams which added millions of dollars to the bottom line of companies in the midwestern United States. These studies are described in Chapters 9 and 17. Also, this text contains more than 100 other examples which either contain real world data or are motivated by real problems.

An analysis of all six sigma improvement studies conducted in two years at a medium-sized midwestern manufacturer is described in Chapter 21. In that study, 25 of the 34 projects generated reasonable profits. Also, the structure afforded by the methods presented in this book appeared to aid in the generation of extremely high profits in two of the cases. The profits from these projects alone could be viewed as strong justification for the entire six sigma program.

## 1.7 Overview of this Book

This book is divided into three major parts. The first part describes many of the most widely used methods in the area of study called "statistical quality control" (SQC). The second part described formal techniques for data collection and analysis. These techniques are often refered to as "design of experiments" (DOE) methods. Model fitting after data are collected is an important subject by itself. For this reason, many of the most commonly used model-fitting methods are also described in this part with an emphasis on linear regression.

Part III concludes with a description of optimization methods, including their relationship to the planning of six sigma projects. Optimization methods can play an important role both for people working on a six sigma project and for the design of novel statistical methods to help future quality improvement projects.

Case studies are described near the end of each major part and are associated with exercises that ask the reader "What would you have done?" These studies were based largely on my own experiences working with students at midwestern companies during the last several years. In describing the case studies, the intent is to provide the same type of real world contextual information encountered by students, from the engineering specifics and unnecessary information to the millions of dollars added to the bottom line.

It is important for readers to realize that only a minimal amount of "statistical theory" is needed to gain benefits from most of the methods in this book. Theory is helpful mainly for curious readers to gain a deeper appreciation of the methods and for designing new statistical and optimization methods. For this reason, statistical theory is separated to a great extent from a description of the methods. Readers wary of calculus and probability need not be deterred from using the methods.

In the 1950s, a committee of educators met and defined what is now called "Bloom's Taxonomy" of knowledge (Bloom 1956). This taxonomy is often associated with both good teaching and six sigma-related instruction. Roughly speaking, general knowledge divides into: (1) *knowledge* of the needed terminology and the typical applications sequences, (2) *comprehension* of the relevant plots and tables, (3) experience with *application* of several central approaches, (4) an ability for *analysis* of how certain data collection plans are linked to certain model-fitting and decision-making approaches, and (5) the *synthesis* needed to select an appropriate methodology for a given problem, in that order. Critiquing the knowledge being learned and its usefulness is associated with the steps of analysis and/or synthesis. The central thesis associated with Bloom's Taxonomy is that teaching should ideally begin with the knowledge and comprehension and build up to applications, ending with synthesis and critique.

Thus, Bloom's "taxonomy of cognition" divides knowledge and application from theory and synthesis, a division followed roughly in this book. Admittedly, the approach associated with Bloom's taxonomy does not cater to people who prefer to begin with general theories and then study applications and details.

## 1.8 References

Bloom BS (ed.) (1956) Taxonomy of Educational Objectives. (Handbook I: Cognitive Domain). Longmans, Green and Co., New York

Clausing D (1994) Total Quality Development: A Step-By-Step Guide to World-Class Concurrent Engineering. ASME Press, New York

Collins, J (2001) Good to Great: Why Some Companies Make the Leap... and Others Don't. Harper-Business, New York

Czitrom V (1999) One-Factor-at-a-Time Versus Designed Experiments. The American Statistician 53 (2):126-131

Fisher RA. (1925) Statistical Methods for Research Workers. Oliver and Boyd, London

Hahn, GJ, Hill, WJ, Hoer, RW, and Zinkgraft, SA (1999) The Impact of Six Sigma Improvement--A Glimpse into the Future of Statistics. The American Statistician, 532:208-215.

Harry MJ, Schroeder R (1999) Six Sigma, The Breakthrough Management Strategy Revolutionizing The World's Top Corporations. Bantam Doubleday Dell, New York

Hazelrigg G (1996) System Engineering: An Approach to Information-Based Design. Prentice Hall, Upper Saddle River, NJ

Kaynak H (2003) The relationship between total quality management practices and their effects on firm performance. The Journal of Operations Management 21:405-435

Linderman K, Schroeder RG, Zaheer S, Choo AS (2003) Six Sigma: a goal-theoretic perspective. The Journal of Operations Management 21:193-203

Pande PS, Neuman RP, Cavanagh R (2000) The Six Sigma Way: How GE, Motorola, and Other Top Companies are Honing Their Performance. McGraw-Hill, New York

Taguchi G (1993) Taguchi Methods: Research and Development. In: Konishi S (ed.) Quality Engineering Series, vol 1. The American Supplier Institute, Livonia, MI

Welch J, Welch S (2005) Winning. HarperBusiness, New York

Womack JP, Jones DT (1996) Lean Thinking. Simon & Schuster, New York

Womack JP, Jones DT, Roos D (1991) The Machine that Changed the World: The Story of Lean Production. Harper-Business, New York

## 1.9 Problems

In general, pick the correct answer that is most complete.

1. Consider the toy system of paper airplanes. Which of the following constitute possible design KIVs and KOVs?
   a. KIVs include time unit flies dropped from 2 meters and KOVs include wing fold angle.
   b. KIVs include wing fold angle in design and KOVs include type of paper in design.

   c. KIVs include wing fold angle and KOVs include time unit flies assuming a 2 meters drop.
   d. Answers in parts “a” and “b” are both correct.
   e. Answers in parts “a” and “c” are both correct.

2. Consider a system that is your personal homepage. Which of the following constitute possible design KIVs and KOVs?
   a. KIVs include background color and KOVs include time it takes to find your resume.
   b. KIVs include expert rating (1-10) of site and KOVs include amount of flash animation.
   c. KIVs include amount of flash animation and KOVs include expert rating (1-10) of site.
   d. Answers in parts “a” and “b” are both correct.
   e. Answers in parts “a” and “c” are both correct.

3. Assume that you are paid to aid with decision-making about settings for a die casting process in manufacturing. Engineers are frustrated by the amount of flash or spill-out they must clean off the finished parts and the deviations of the part dimensions from the nominal blueprint dimensions. They suggest that the preheat temperature and injection time might be changeable. They would like to improve the surface finish rating (1-10) but strongly doubt whether any factors would affect this. Which of the following constitute KIVs and KOVs?
   a. KIVs include deviation of part dimensions from nominal and KOVs include surface finish rating.
   b. KIVs include preheat temperature and KOVs include deviation of part dimensions from nominal.
   c. KIVs include surface finish rating and KOVs include deviation of part dimensions from nominal.
   d. Answers in parts “a” and “b” are both correct.
   e. Answers in parts “a” and “c” are both correct.

4. You are an industrial engineer at a hospital trying to reduce waiting times of patients in emergency rooms. You are allowed to consider the addition of one nurse during peak hours as well as subscription to a paid service that can reduce data entry times. Which of the following constitute KIVs and KOVs?
   a. KIVs include subscription to a data entry service and KOVs include waiting times.
   b. KIVs include number of nurses and KOVs include average waiting times for patients with AIDS.
   c. KIVs include average waiting times and KOVs include number of nurses.
   d. Answers in parts “a” and “b” are both correct.
   e. Answers in parts “a” and “c” are both correct.

5. Consider your friend’s system relating to grade performance in school. List two possible KIVs and two possible KOVs.

6. Consider a system associated with international wire transfers in personal banking. List two possible KIVs and two possible KOVs.

7. According to Chapter 1, which of the following should be included in the definition of six sigma?
    a. Each project must be cost justified.
    b. For new products, project phases should be organized using DMADV.
    c. 3.4 unacceptable units per million opportunities is the generic goal.
    d. Answers in parts "a" and "b" are both correct.
    e. Answers in parts "a" and "c" are both correct.

8. According to Chapter 1, which of the following should be included in the definition of six sigma?
    a. Fear should be driven out of the workplace.
    b. Participants do not need to become statistics experts.
    c. Thorough SOP documentation must be completed at the end of every project.
    d. Answers in parts "a" and "b" are both correct.
    e. Answers in parts "a" and "c" are both correct.

9. How does six sigma training differ from typical university instruction? Explain in two sentences.

10. List two perceived problems associated with TQM that motivated the development of six sigma.

11. Which of the following is the lean production way to making three sandwiches?
    a. Lay out six pieces of bread, add tuna fish to each, add mustard, fold all, and cut.
    b. Lay out two pieces of bread, add tuna fish, mustard, fold, and cut. Repeat.
    c. Lay out the tuna and mustard, order out deep-fat fried bread and wait.
    d. Answers in parts "a" and "b" are both correct.
    e. Answers in parts "a" and "c" are both correct.

12. Which of the following were innovations associated with mass production?
    a. Workers did not need much training since they had simple, small tasks.
    b. Guild certification built up expertise among skilled tradesmen.
    c. Interchangeability of parts permitted many operations to be performed usefully at one time without changing over equipment.
    d. Answers in parts "a" and "b" are both correct.
    e. Answers in parts "a" and "c" are both correct.

13. In two sentences, explain the relationship between mass production and lost accountability.

14. In two sentences, explain why Shewhart invented control charts.

15. In two sentences, summarize the relationship between lean production and quality.

16. Give an example of a specific engineered system and improvement system that might be relevant in your work life.

17. Provide one modern example of craft production and one modern example of mass production. Your examples do not need to be in traditional manufacturing and could be based on a task in your home.

18. Which of the following are benefits of freezing a design long before Job 1?
    a. Your design function can react to data after Job 1.
    b. Tooling costs more because it becomes too easy to do it correctly.
    c. It prevents reactive design tinkering and therefore reduces tooling costs.
    d. Answers in parts "a" and "b" are both correct.
    e. Answers in parts "a" and "c" are both correct.

19. Which of the following are benefits of freezing a design long before Job 1?
    a. It encourages people to be systematic in attempts to avoid problems.
    b. Design changes cost little since tooling has not been committed.
    c. Fire-fighting occurs more often.
    d. Answers in parts "a" and "b" are both correct.
    e. Answers in parts "a" and "c" are both correct.

20. Which of the following are perceived benefits of being ISO certified?
    a. Employees must share information and agree on which practices are best.
    b. Inventory is reduced because there are smaller batch sizes.
    c. Training costs are reduced since the processes are well documented.
    d. Answers in parts "a" and "b" are both correct.
    e. Answers in parts "a" and "c" are both correct.

21. Which of the following are problems associated with gaining ISO accreditation?
    a. Resources must be devoted to something not on the value stream.
    b. Managers may be accused of "tree hugging" because fear can be useful.
    c. Employees rarely feel stifled because of a bureaucratic hurdles are eliminated.
    d. Answers in parts "a" and "b" are both correct.

   e. Answers in parts "a" and "c" are both correct.

22. According to Bloom's Taxonomy, which of the following is true?
    a. People almost always learn from the general to the specific.
    b. Learning of facts, application of facts, and the ability to critique, in that order, is easiest.
    c. Theory is critical to being able to apply material.
    d. Answers in parts "a" and "b" are both correct.
    e. Answers in parts "a" and "c" are both correct.

23. According to Bloom's Taxonomy which of the following would be effective?
    a. Give application experience, and then teach them theory as needed.
    b. Ask people to critique your syllabus content immediately, and then teach facts.
    c. Start with facts, then application, then some theory, and then ask for critiques.
    d. Answers in parts "a" and "b" are both correct.
    e. Answers in parts "a" and "c" are both correct.

24. Suppose one defines two basic levels of understanding of the material in this book to correspond to "green belt" (lower) and "black belt" (higher). Considering Bloom's Taxonomy, and inspecting this book's table of contents, what types of knowledge and abilities would a green belt have and what types of knowledge would a black belt have?

25. Suppose you were going to teach a fifteen year old about your specific major and its usefulness in life. Provide one example of knowledge for each level in Bloom's Taxonomy.

26. According to the chapter, which is correct and most complete?
    a. TQM has little to do with technology transfer from Europe to the U.S.
    b. The perception that TQM is anti-business developed in the last five years.
    c. One of Deming's 14 points is that fear is a necessary evil.
    d. All of the above are correct.
    e. All of the above are correct except (a) and (d).