

CHAPTER 2

Principles of Six Sigma

Teaching Notes

This chapter brings the Six Sigma principles and concepts into a sharp focus, and builds on the need to integrate a performance management framework with operational requirements in managing quality. In this chapter, we introduce the statistical basis for Six Sigma, and outline the requirements for Six Sigma implementation. Key objectives for this chapter should be to assist students:

- To define the Six Sigma Body of Knowledge and show how it is being used as an integrating framework for this textbook.
- To appreciate that there is a need for organizations to align Six Sigma projects with an organization's strategy, and address any perceived weaknesses or threats that may have been identified during the strategic planning process.
- To understand that a problem is defined as: a deviation between what should be happening and what actually is happening that is important enough to make someone think the deviation ought to be corrected.
- To learn to classify quality problems into one of five categories, including: a) *conformance problems*, b) *efficiency problems*, c) *unstructured performance problems*, d) *product design problems*, and e) *process design problems*.
- To learn that Six Sigma can be applied to a wide variety of transactional, administrative, and service areas in addition to manufacturing. However, differences between services and manufacturing make opportunities in services more difficult to identify, and projects more difficult to define. Small organizations can use Six Sigma, although perhaps in a more informal fashion.

- To apply Six Sigma processes and concepts to service processes to enhance one of four key measures of performance:
 - *Accuracy*, as measured by correct financial figures, completeness of information, or freedom from data errors
 - *Cycle time*, which is a measure of how long it takes to do something, such as pay an invoice
 - *Cost*, that is, the internal cost of process activities (in many cases, cost is largely determined by the accuracy and/or cycle time of the process; the longer it takes, and the more mistakes that have to be fixed, the higher the cost)
 - *Customer satisfaction*, which is typically the primary measure of success
- To reinforce the definition of a process as “a fundamental way of viewing work in an organization” (from Chapter 1) and to develop the concept of a set of processes, which together, form a **system** – an integrated set of activities within an organization that work together for the aim of the organization.
- To develop the classifications of processes as:
 1. **Value-creation processes** (sometimes called *core processes*), which are most important to “running the business” and maintaining or achieving a sustainable competitive advantage, and
 2. **Support processes**, which those that contribute to the successful performance of an organization’s value-creation processes, employees, and daily operations.
- To understand the definitions and importance of variation in Six Sigma processes, including: factors which are present as a natural part of a process and are referred to as **common causes** of variation. Common causes are a result of the design of the product and production system and generally account for about 80 to 95 percent of the observed variation in the output of a production process. AND The remaining variation in a production process is the result of **special causes**, often called **assignable causes** of variation. Special causes arise from external sources that are not inherent in the process. They appear sporadically and disrupt the random pattern of common causes.
- To learn that in Six Sigma terminology, a **nonconformance** is any defect or error that is passed on to the customer. In manufacturing we often use the term **defect**, and in service applications, we generally use the term **error** to describe a nonconformance.
- A **nonconforming unit of work** is one that has one or more defects or errors. For discrete data, the two important metrics are the **proportion nonconforming** and **nonconformances per unit (NPU)**.
- A common measure of output quality is **defects per unit (DPU)**, computed as Number of defects discovered/Number of units produced, and in Six Sigma metrics, **defects per**

million opportunities (dpmo) = $DPU \times 1000000/\text{opportunities for error}$. A six-sigma quality level corresponds to at most 3.4 dpmo.

- To learn that quality in processes has a cumulative impact, where the quality output at each stage in the process must be considered. If a process consists of many steps, each step may create nonconformances, thus reducing the yield of the final output. One measure that is often used to evaluate the quality of the entire process is **rolled throughput yield (RTY)**. RTY is the proportion of conforming units that results from a series of process steps. Mathematically, it is the product of the yields from each process step.
- To appreciate that a structured problem solving process provides employees and teams with a common language and a set of tools to communicate with each other. The Six Sigma DMAIC methodology process provides this type of roadmap for conducting a Six Sigma project.
- To develop understanding of the Six Sigma stages of: 1) Define - the process of drilling down to a more specific problem statement is sometimes called **project scoping**; 2) Measure - collecting good data, observation, and careful listening; 3) Analyze - focuses on *why* defects, errors, or excessive variation occur, and focuses on the **root cause**; 4) Improve - focuses on idea generation, evaluation, and selection; 5) Control - focuses on how to maintain the improvements.
- To learn about Lean Six Sigma, defined as an integrated improvement approach to improve goods and services and operations efficiency by reducing defects, variation, and waste; and to apply classification of different types of **muda** (waste), and **Kaizen events** to lean Six Sigma projects.
- To define lean tools and learn how they can be used to develop a lean organization.
- To understand how Six Sigma and Lean complement one another and how they are converging.

ANSWERS TO REVIEW QUESTIONS

1. Briefly summarize the Six Sigma Body of Knowledge.

Ans. Six Sigma encompasses a vast collection of concepts, tools, and techniques that are drawn from many areas of business, statistics, engineering, and practical experience. Many of these subjects are technical; others deal with management and organizational issues. Practitioners need a balanced set of both the “hard” and the “soft” disciplines in order to apply and implement Six Sigma effectively. (See list in the body of the chapter for more details.)

2. Describe the principal sources of ideas for Six Sigma projects.

Ans. Ideas for Six Sigma projects stem from many sources. Often, they are driven by needs and opportunities to achieve an organization's strategic goals, objectives, and action plans by which it seeks to create a competitive advantage. Six Sigma projects also stem from the fundamental need to improve results, captured in measures such as profit, market share, customer satisfaction, operational efficiency, product innovation, and quick response.

3. What are dashboards and balanced scorecards? How do they support Six Sigma projects?

Ans. Dashboards typically consist of a small set of measures (five or six) that provide a quick summary of process performance. This term stems from the analogy to an automobile's dashboard—a collection of indicators (speed, RPM, oil pressure, temperature, etc.) that summarize key performance measures. Dashboards often use graphs, charts, and other visual aids to communicate key measures and alert workers and managers when performance is not where it should be.

The balanced scorecard is a summary of broad performance measures across the organization. The purpose of the balanced scorecard is “to translate strategy into measures that uniquely communicate your vision to the organization.” A balanced scorecard defines the most important drivers of organizational success and consists of four perspectives:

- *Financial Perspective*: Measures the ultimate results that the business provides to its shareholders.
- *Internal Perspective*: Focuses attention on the performance of the key internal processes that drive the business.
- *Customer Perspective*: Focuses on customer needs and satisfaction as well as market share.
- *Innovation and Learning Perspective*: Directs attention to the basis of a future success—the organization's people and infrastructure..

Dashboards and scorecards provide rich sources of information for tracking progress. Results that are inferior to competitor's performance, or which exhibit adverse trends often suggest the need for Six Sigma improvement projects.

4. List and briefly define the five categories of quality-related problem types. What are the best approaches for attacking each of these types of problems?

Ans. Research using more than a thousand applicable published cases suggests that virtually every instance of quality-related problem-solving falls into one of five categories:

1. *Conformance problems*, which are characterized by unsatisfactory performance that causes customer dissatisfaction, such as high levels of defects, service failures, or customer complaints. The processes that create these results are typically well-specified and can be

easily described.

2. *Efficiency problems*, which are characterized by unsatisfactory performance that causes dissatisfaction from the standpoint of noncustomer stakeholders, such as managers of financial or supply chain functions. Typical examples are high cost, excessive inventory, low productivity, and other process inefficiencies.

3. *Unstructured performance problems*, which are characterized by unsatisfactory performance by processes that are not well-specified or understood. For example, a company might discover that employee turnover is much higher than desired or employee satisfaction is low. The factors that contribute to such results do not stem from processes that can easily be described.

4. *Product design problems*, which involve designing new products or redesigning existing products to better satisfy customer needs.

5. *Process design problems*, which involve designing new processes or substantially revising existing processes. These might include new factory processes to manufacture a new product line or designing a more flexible assembly line.

Each of these categories of problems requires different approaches and methodologies. Traditional Six Sigma methods are most applicable to conformance problems because the processes that create the problems can be easily identified, measured, analyzed, and changed. For efficiency problems, lean tools, which evolved from the Toyota production system, are generally used. Unstructured performance problems require more creative approaches to solving them. For product and process design problems, special tools and methods or a combination of many of these approaches are used (and fall under the scope of DFSS – Design for Six Sigma). As Six Sigma has evolved, all of these tools and approaches have been consolidated into the Six Sigma body of knowledge, making it a powerful approach for any level of organizational problem solving.

5. Explain the application of Six Sigma in service organizations. How does it differ from manufacturing? How is it similar?

Ans. Applying Six Sigma to services requires examination of four key measures of the performance:

- *Accuracy*, as measured by correct financial figures, completeness of information, or freedom from data errors
- *Cycle time*, which is a measure of how long it takes to do something, such as pay an invoice
- *Cost*, that is, the internal cost of process activities (in many cases, cost is largely determined by the accuracy and/or cycle time of the process; the longer it takes, and the more mistakes that have to be fixed, the higher the cost)
- *Customer satisfaction*, which is typically the primary measure of success

While Six Sigma applies equally well in service areas as in manufacturing, it is true that services have some unique characteristics. First, the culture of a service firm is usually less scientific, and service employees typically do not think in terms of processes,

measurements, and data. The processes are often invisible, complex, and not well defined or well documented. Also, the work typically requires considerable human intervention, such as customer interaction, underwriting or approval decisions, or manual report generation. These differences make opportunities difficult to identify, and projects difficult to define. Finally, similar service activities are often done in different ways. If you have three people doing the same job, perhaps in three different locations, it is unlikely that they will do the job in the same way. It should be noted that within the service sector, Six Sigma is beginning to be called **transactional Six Sigma**.

6. What are process owners and stakeholders? How are they different from each other?

Ans. Individuals or groups, known as **process owners**, are accountable for process performance and have the authority to control and improve their process. Process owners may range from high-level executives who manage cross-functional processes to workers who run a manufacturing cell or an assembly operation on the shop floor. They are important members of Six Sigma project teams because of their understanding of and involvement in processes. Other individuals or groups, called **stakeholders**, are or might be affected by an organization's actions and success; thus, they are vital to a Six Sigma project. Stakeholders might include customers, the workforce, partners, collaborators, governing boards, stockholders, donors, suppliers, taxpayers, regulatory bodies, policy makers, funders, and local and professional communities.

7. Define the two general categories of processes in any organization and provide examples of each.

Ans. The two general categories of processes and examples are:

1. **Value-creation processes** (sometimes called *core processes*), which are most important to “running the business” and maintaining or achieving a sustainable competitive advantage, and
2. **Support processes**, which those that contribute to the successful performance of an organization's value-creation processes, employees, and daily operations.

Value-creation processes drive the creation of products and services, are critical to customer satisfaction, and have a major impact on the strategic goals of an organization. They typically include design, production/delivery, and other critical business processes.

Support processes provide infrastructure for value-creation processes but generally do not add value directly to the product or service. A process such as order entry that might be thought of as a value creation process for one company (e.g., a direct mail distributor) might be considered as a support process for another (e.g., a custom manufacturer). In general, value creation processes are driven by external customer needs while support processes are driven by internal customer needs. Because value creation processes do add value to products and services, they require a higher level of attention than do support processes.

8. What are process requirements and how can they be identified?

Ans. Understanding the requirements that processes should meet is vital to improving them. Given the diverse nature of value-creation processes, the requirements and performance characteristics might vary significantly for different processes. In general, value-creation process requirements are driven by consumer or external customer needs. For example, if hotel customers expect fast, error-free check-in, then the check-in process must be designed for speed and accuracy. Support process requirements, on the other hand, are driven by internal customer needs and must be aligned with the needs of key value creation processes. For example, information technology processes at a hotel must support the check-in process requirements of speed and accuracy; this would require real-time information on room availability.

9. Explain the concept of variation in processes. State the primary sources of process variation.

Ans. Any process contains many sources of variation. In manufacturing, for example, different lots of material vary in strength, thickness, or moisture content. Cutting tools have inherent variation in their strength and composition. Even when measurements of several items by the same instrument are the same, it is due to a lack of precision in the measurement instrument; extremely precise instruments always reveal slight differences. Similar variation occurs in services, particularly as a result of inconsistency in human performance and the interface with technology.

10. Explain the difference between common and special cause of variation and provide some examples.

Ans. The complex interactions of these variations in materials, tools, machines, operators, and the environment are not easily understood. Variation due to any of these individual sources appears at random; individual sources cannot be identified or explained. However their combined effect is stable and can usually be predicted statistically. These factors are present as a natural part of a process and are referred to as **common causes** of variation. Common causes are a result of the design of the product and production system and generally account for about 80 to 95 percent of the observed variation in the output of a production process. Therefore, common cause variation can only be reduced if the product is redesigned, or if better technology or training is provided for the production process.

The remaining variation in a production process is the result of **special causes**, often called **assignable causes** of variation. Special causes arise from external sources that are not inherent in the process. They appear sporadically and disrupt the random pattern of common causes. Hence, they tend to be easily detectable using statistical methods, and usually economical to correct. Unusual variation that results from isolated incidents can be explained or corrected. A system governed only by common causes is called a **stable**

system. Understanding a stable system and the differences between special and common causes of variation is essential for managing any system.

11. What operational problems are caused by excessive variation?

Ans. Excessive variation can result in various “evils,” including:

- *Variation increases unpredictability.* If we don’t understand the variation in a system, we cannot predict its future performance.
- *Variation reduces capacity utilization.* If a process has little variability, then managers can increase the load on the process because they do not have to incorporate slack into their production plans.
- *Variation contributes to a “bullwhip” effect.* This well-known phenomenon occurs in supply chains; when small changes in demand occur, the variation in production and inventory levels becomes increasingly amplified upstream at distribution centers, factories, and suppliers, resulting in unnecessary costs and difficulties in managing material flow.
- *Variation makes it difficult to find root causes.* Process variation makes it difficult to determine whether problems are due to external factors such as raw materials or reside within the processes themselves.
- *Variation makes it difficult to detect potential problems early.* Unusual variation is a signal that problems exist; if a process has little inherent variation, then it is easier to detect when a problem actually does occur.

The evils of variation can be addressed by understanding the process and searching for, and eliminating, root causes.

12. Explain Deming’s red bead and funnel experiments. What lessons do they provide?

Ans. The late W. Edwards Deming explained these concept relating to variation using two simple, yet powerful experiments, the Red Bead and Funnel experiments, in his four-day management seminars.

The Red Bead experiment proceeds as follows. A Foreman (usually Deming) selects several volunteers from the audience: Six Willing Workers, a Recorder, two Inspectors, and a Chief Inspector. The materials for the experiment include 4,000 wooden beads—800 red and 3,200 white—and two Tupperware boxes, one slightly smaller than the other. Also, a paddle with 50 holes or depressions is used to scoop up 50 beads, which is the prescribed workload. In this experiment, the company is “producing” beads for a new customer who needs only white beads and will not take red beads. The Foreman explains that everyone will be an apprentice for three days to learn the job. During apprenticeship, the workers may ask questions. Once production starts, however, no questions are allowed. The procedures are rigid; no departures from procedures are permitted so that no variation in performance will occur. The Foreman explains to the Willing Workers that their jobs

depend on their performance and if they are dismissed, many others are willing to replace them. Furthermore, no resignations are allowed. The company's work standard, the Foreman explains, is 50 beads per day.

The production process is simple: Mix the raw material and pour it into the smaller box. Repeat this procedure, returning the beads from the smaller box to the larger one. Grasp the paddle and insert it into the bead mixture. Raise the paddle at a 44-degree angle so that every depression will hold a bead. The two Inspectors count the beads independently and record the counts. The Chief Inspector checks the counts and announces the results, which are written down by the Recorder. The Chief Inspector then dismisses the worker. When all six Willing Workers have produced the day's quota, the Foreman evaluates the results. During "production" Deming would berate the poor performers and reward the good performers. He would try to motivate them to do better, knowing, of course, that they would not be able to affect the results.

This experiment leads to several important lessons about statistical thinking:

- *Variation exists in systems and, if stable, can be predicted.*
- *All the variation in the production of red beads, and the variation from day to day of any Willing Worker, came entirely from the process itself.*
- *Numerical goals are often meaningless.*
- *Management is responsible for the system.*

Deming's second experiment is the Funnel Experiment. Its purpose is to show that people can and do affect the outcomes of many processes and create unwanted variation by "tampering" with the process, or indiscriminately trying to remove common causes of variation. In this experiment, a funnel is suspended above a table with a target drawn on a tablecloth. The goal is to hit the target. Participants drop a marble through the funnel and mark the place where the marble eventually lands. Rarely will the marble rest on the target. This variation is due to common causes in the process. One strategy is to simply leave the funnel alone, which creates some variation of points around the target. This may be called:

Rule 1. However, many people believe they can improve the results by adjusting the location of the funnel. Three other possible rules for adjusting the funnel are:

Rule 2. Measure the deviation from the point at which the marble comes to rest and the target. Move the funnel an equal distance in the opposite direction from its current position.

Rule 3. Measure the deviation from the point at which the marble comes to rest and the target. Set the funnel an equal distance in the opposite direction of the error from the target.

Rule 4. Place the funnel over the spot where the marble last came to rest.

Clearly the first rule—leave the funnel alone—results in the least variation. People use these rules inappropriately all the time, causing more variation than would normally occur.

As can be shown by numerous examples, errors are usually compounded by an inappropriate reaction, using rules 2-4. All of these policies stem from a lack of understanding of variation, which originates from not understanding the process.

13. What are metrics, and why are they important?

Ans. A **metric** is a verifiable measurement of some particular characteristic, stated either numerically (e.g., percentage of defects) or in qualitative terms (e.g., level of satisfaction – “poor” or “excellent”). Metrics provide information on performance, allow managers to evaluate performance and make decisions, communication with one another, identify opportunities for improvement, and frame expectations for employees, customers, suppliers, and other stakeholders. Metrics are vital in Six Sigma applications because they facilitate fact-based decisions.

14. Explain the difference between a measure and an indicator.

Ans. **Measures** and **indicators** refer to the numerical information that results from measurement; that is, measures and indicators are numerical values associated with a metric. The term *indicator* is often used for measurements that are not a direct or exclusive measure of performance. For instance, you cannot directly measure dissatisfaction, but you can use the number of complaints or lost customers as indicators of dissatisfaction. Measurements and indicators provide critical information about business performance and are fundamental to Six Sigma.

15. What is the difference between a discrete metric and a continuous metric? Provide some examples.

Ans. A **discrete metric** is countable. For example, a dimension is either within tolerance or out of tolerance, an order is complete or incomplete, or an invoice can have one, two, three, or any number of errors. In quality control terminology, a performance characteristic that is either present or absent in the product or service under consideration is called an **attribute**, and such data are referred to as **attributes data**. Some examples are whether the correct zip code was used in shipping an order; or by comparing a dimension to specifications, such as whether the diameter of a shaft falls within specification limits of 1.60 ± 0.01 inch. They are typically expressed as numerical counts or as proportions. **Continuous metrics**, such as length, time, or weight, are concerned with the degree of conformance to specifications. In quality control, continuous performance characteristics are often called **variables**, and such data are referred to as **variables data**.

16. What is a nonconformance? How does it differ from a nonconforming unit of work?

Ans. A **defect**, or **nonconformance**, is any mistake or error that is passed on to the customer. A **unit of work** is the output of a process or an individual process step. A unit of work might be a completed product ready to ship to a customer, a subassembly, an

individual part produced on a machine, or a package to be delivered to a customer. A **nonconforming unit of work** is one that has one or more defects or errors.

17. Explain how to calculate the dpmo metric.

Ans. A common measure of output quality is **defects per unit (DPU)**, computed as Number of defects discovered/Number of units produced, and in Six Sigma metrics, **defects per million opportunities (dpmo)** = DPU × 1000000/opportunities for error. A six-sigma quality level corresponds to at most 3.4 dpmo.

18. Explain the theoretical basis of a six sigma quality level (3.4 dpmo).

Ans. The theoretical basis for Six Sigma is statistical theory. A six sigma quality level corresponds to a process variation equal half of the design tolerance (in terms of the process capability index, $C_p = 2.0$) while allowing the mean to shift as much as 1.5 standard deviations from the target. The allowance of a shift in the distribution is important, since no process can be maintained in perfect control.

19. What is the difference between throughput yield (TY) and rolled throughput yield (RTY)?

Ans. If nonconformances per unit (NPU) has been calculated and nonconformances occur randomly, we can estimate the number of units that have no nonconformances—called **throughput yield (TY)**—using the following formula:

$$TY = e^{-NPU} \quad (2.7)$$

If a process consists of many steps, each step may create nonconformances, thus reducing the yield of the final output. One measure that is often used to evaluate the quality of the entire process is **rolled throughput yield (RTY)**. RTY is the proportion of conforming units that results from a series of process steps. Mathematically, it is the product of the yields from each process step.

20. What are the key themes common to all problem-solving methodologies?

Ans. Although each methodology is distinctive in its own right, they share many common themes:

1. *Redefining and analyzing the problem*: Collect and organize information, analyze the data and underlying assumptions, and reexamine the problem for new perspectives, with the goal of achieving a workable problem definition.
 2. *Generating ideas*: “Brainstorm” to develop potential solutions.
 3. *Evaluating and selecting ideas*: Determine whether the ideas have merit and will achieve the problem solver’s goal.
 4. *Implementing ideas*: Sell the solution and gain acceptance by those who must use them.
- These themes are reflected in the principal problem solving methodology used by Six

Sigma, DMAIC—define, measure, analyze, improve, and control—which will be discussed further in question 21.

21. Describe the steps in the DMAIC methodology.

Ans. General Electric's approach to Six Sigma implementation uses a problem solving approach (DMAIC) and employs five phases. Under each of these are sub-steps that make up the work for each phase.

- a) Define (D)
 - i) Identify customers and their priorities.
 - ii) Identify a project suitable for Six Sigma efforts based on business objectives as well as customer needs and feedback.
 - iii) Identify CTQ's (critical to quality characteristics) that the customer considers to have the most impact on quality.
- b) Measure (M)
 - i) Determine how to measure the process and how it is performing.
 - ii) Identify the key internal processes that influence CTQ's and measure the defects currently generated relative to those processes
- c) Analyze (A)
 - i) Determine the most likely causes of defects.
 - ii) Understand why defects are generated by identifying the key variables that are most likely to create process variation.
- d) Improve (I)
 - i) Identify means to remove the causes of the defects.
 - ii) Confirm the key variables and quantify their effects on the CTQ's.
 - iii) Identify the maximum acceptable ranges of the key variables and a system for measuring deviations of the variables.
 - iv) Modify the process to stay within the acceptable range.
- e) Control
 - i) Determine how to maintain the improvements.
 - ii) Put tools in place to ensure that the key variables remain within the maximum acceptable ranges under the modified process.

Note that this approach is similar to the other quality improvement approaches and incorporates many of the same ideas. The key difference is the emphasis placed on customer requirements and the use of statistical tools and methodologies.

22. What is project scoping? Why is it important to good problem solving?

Ans. The process of drilling down to a more specific problem statement is sometimes called **project scoping**. The general nature of the problem is usually described in the project charter, but is often rather vague. One must describe the problem in very specific operational terms that facilitate further analysis. In addition, A good problem statement

should also identify customers and the CTQs that have the most impact on product or service performance, describe the current level of performance or the nature of errors or customer complaints, identify the relevant performance metrics, benchmark best performance standards, calculate the cost/revenue implications of the project, and quantify the expected level of performance from a successful Six Sigma effort.

23. How does Lean Six Sigma differ from the traditional concept of Six Sigma?

Ans. As organizations developed Six Sigma capabilities to address conformance problems, they began to realize that many important business problems fell into the category of efficiency problems and assigned these problems to Six Sigma experts and project teams. As a result, Six Sigma teams began to use tools of lean production to improve process efficiency. As the tools of Six Sigma and lean production merged, the concept of **Lean Six Sigma (LSS)** emerged, drawing upon the best practices of both approaches. Lean Six Sigma can be defined as an integrated improvement approach to improve goods and services and operations efficiency by reducing defects, variation, and waste.

24. Explain the principles of lean thinking and the seven categories of waste.

Ans. **Lean thinking** refers to approaches that focus on the elimination of waste in all forms, and smooth, efficient flow of materials and information throughout the value chain to obtain faster customer response, higher quality, and lower costs. A simple way of defining it is “getting more done with less.” In any process, activities may be classified as value-added or non-value-added. Lean thinking considers non-value-added activities as waste, or to use the common Japanese term, *muda*.

The Toyota Motor Company classified waste into seven major categories:

1. *Overproduction*
2. *Waiting time*
3. *Unnecessary transportation*
4. *Unnecessary processing*
5. *Inventory*
6. *Unnecessary motion*
7. *Production defects*

Lean approaches focus on the elimination of waste in all these forms throughout the entire value chain to achieve faster customer response, reduced inventories, higher quality, and better human resources.

25. What is a kaizen event?

Ans. Lean improvements are often implemented using kaizen events. A **kaizen event** is an intense and rapid improvement process in which a team or a department throws all its

resources into an improvement project over a short time period, as opposed to traditional kaizen applications, which are performed on a part-time basis.

26. Describe the principal tools used in lean production.

Ans. The principal tools used in lean production include:

- *The 5S's*. The 5S's are derived from Japanese terms: *seiri* (sort), *seiton* (set in order), *seiso* (shine), *seiketsu* (standardize), and *shitsuke* (sustain). They define a system for workplace organization and standardization.
- *Visual controls*. Visual controls are indicators for tools, parts, and production activities that are placed in plain sight of all workers so that everyone can understand the status of the system at a glance. Thus, if a machine goes down, or a part is defective or delayed, immediate action can be taken.
- *Efficient layout and standardized work*. The layout of equipment and processes is designed according to the best operational sequence, by physically linking and arranging machines and process steps most efficiently, often in a cellular arrangement. Standardizing the individual tasks by clearly specifying the proper method reduces wasted human movement and energy.
- *Pull production*. In this system (also known as *kanban* or *just-in-time*), upstream suppliers do not produce until the downstream customer signals a need for parts.
- *Single minute exchange of dies (SMED)*. SMED refers to rapid changeover of tooling and fixtures in machine shops so that multiple products in smaller batches can be run on the same equipment. Reducing setup time adds value to the operation and facilitates smoother production flow.
- *Total productive maintenance*. Total productive maintenance is designed to ensure that equipment is operational and available when needed.
- *Source inspection*. Inspection and control by process operators guarantees that product passed on to the next production stage conforms to specifications.
- *Continuous improvement*. Continuous improvement provides the link to Six Sigma. In order to make lean production work, one must get to the root causes of problems and permanently remove them. Teamwork is an integral part of continuous improvement in lean environments. Many techniques that we discuss in subsequent chapters are used.

27. What is the Theory of Constraints (TOC)? Briefly explain the key principles.

Ans. The **Theory of Constraints (TOC)** is a set of principles that focuses on increasing process throughput by maximizing the utilization of all bottleneck activities in a process. Throughput is commonly defined as the average number of goods or services completed per time period in a process. TOC views throughput as the amount of money generated per time period through actual sales. For most business organizations the goal is to maximize throughput, thereby maximizing cash flow. Inherent in this definition is that it makes little sense to make a good or service until it can be sold, and that excess inventory is wasteful. Thus, TOC supports lean thinking.

In TOC, a **constraint** is anything in an organization that limits it from moving toward or achieving its goal. Constraints determine the throughput of a facility, because they limit production output to their own capacity. There are two basic types of constraints: physical and nonphysical. A physical constraint is associated with the capacity of a resource such as a machine, employee, or workstation. Physical constraints result in process bottlenecks. A bottleneck work activity is one that effectively limits the capacity of the entire process. At a bottleneck, the input exceeds the capacity, restricting the total output that is capable of being produced. A nonbottleneck work activity is one in which idle capacity exists. A nonphysical constraint is environmental or organizational, such as low product demand or an inefficient management policy or procedure. Inflexible work rules, inadequate labor skills, and poor management are all forms of constraints.

Because the number of constraints is typically small, the TOC focuses on identifying them, managing bottleneck and nonbottleneck work activities, linking them to the market to ensure an appropriate product mix, and scheduling the NBN resources to enhance throughput.

28. What are the differences between lean and Six Sigma?

Ans. Both Six Sigma and lean are driven by customer requirements, focus on real dollar savings, have the ability to make significant financial impacts on the organization, and can easily be used in non-manufacturing environments. Both exploit data and logical problem-solving analysis.

Some differences clearly exist between lean and Six Sigma. First, they attack different types of problems. Lean addresses visible problems in processes, for example, inventory, material flow, and safety. Six Sigma is more concerned with less visible problems, for example, variation in performance. In essence, lean is focused on efficiency by reducing waste and improving process flow, whereas Six Sigma is focused on effectiveness by reducing errors and defects. Another difference is that lean tools are more intuitive and easier to apply by anybody in the workplace, whereas many Six Sigma tools require advanced training and expertise of Black Belt or Master Black Belt specialists (or consultant equivalents). For example, the concept of the 5S's is easier to grasp than statistical methods. Thus, organizations might be well-advised to start with basic lean principles and evolve toward more sophisticated Six Sigma approaches. However, it is important to integrate both approaches with a common goal—improving business results.

ANSWERS TO DISCUSSION QUESTIONS

1. Review the Six Sigma Body of Knowledge. What topics have you covered in previous courses at your school? Which topics are new to you?

Ans. Answers will vary, depending on curriculum. Most business programs include requirements for statistics, organization behavior (leadership and teams), and operations management (process design and improvement, lean management, statistical process control, TQM, project management concepts). Others may have more depth with advanced statistics, such as design of experiments, or provide a “stand-alone” project management course. A “capstone” course is generally required, where students are introduced to strategic planning and certain aspects of business results.

2. How might you apply the concepts of dashboards and balanced scorecards to your personal life?

Ans. As noted earlier, a dashboard can be thought of as a collection of indicators that summarize key performance measures. Key personal measures might be developed to include health, family relationships, skill development (career and personal), career success, financial well-being, and spiritual balance. Specific health measures could be weight and number of hours per week of exercise. Family relationships could be measured by hours of quality time with each family member. Skill development could be counted in the number of course and seminars completed, to name a few.

The balanced scorecard is a summary of broad performance measures across the organization. The purpose of the balanced scorecard is “to translate strategy into measures that uniquely communicate your vision to the organization.” A balanced scorecard defines the most important drivers of organizational success and consists of four perspectives:

- *Financial Perspective*: Measures the ultimate results that the business provides to its shareholders.
- *Internal Perspective*: Focuses attention on the performance of the key internal processes that drive the business.
- *Customer Perspective*: Focuses on customer needs and satisfaction as well as market share.
- *Innovation and Learning Perspective*: Directs attention to the basis of a future success—the organization’s people and infrastructure.

When applied to career planning, the balance scorecard could be a very valuable tool for tracking performance against a strategic career plan. For example, the financial perspective could be applied to tracking an individual’s income against one, three, and five year goals. The internal perspective could match the results of periodic performance review outcomes versus desired or anticipated results. Customer needs and perspectives would have to be related to a defined set of customers (supervisors to whom one reports, colleagues with whom one interacts, outside customers or suppliers, etc.), and appropriate measures developed. The innovation and learning perspective could be used to measure skill and experience development, also versus a plan for accomplishment of those objectives.

3. Discuss some of the key processes associated with the following business activities for a typical company: sales and marketing, supply chain management, managing information technology, and managing human resources.

Ans. Key business processes for sales and marketing could include the process for identifying and selling products/services to customers; another one for order handling and processing for repeat sales; supply chain management that requires processes for ordering routine and special materials and supplies; and information technology management that requires processes to develop computer systems and programs. Other processes are needed to handle routine, repetitive processing jobs, such as payrolls; and HRM requires processes for recruiting, hiring, orienting new hires, performance review, and employee separation, among others. See below for a more extensive view.

4. List some of the common processes that a student performs. What would the requirements of these processes be? What types of variation exist in these processes? How can these processes be improved using a Six Sigma approach?

Ans. Students in a Six Sigma course might perform a personal TQM project and be asked to identify a number of processes with objectives for improvement. Some processes might be to get ready for class, course preparation, eating a healthy diet, etc. Some typical objectives are get up on time (no snooze alarm), study chapters before coming to class, eat no more than one “junk food” item out of the vending machine each day, etc. The requirements of such processes would be to determine the goal or objective, measure the actual versus the goal, determine the “gap” between those two measures, and take corrective action. Depending on the habits of the individual, the variation might be quite large. For example, if a student had been in the habit of “cramming” for exams, consistent, regular study over the entire term might be difficult and lead to large variations.

Students might use the DMAIC process in order to make improvements. To do so, they would need to define the “critical to quality” characteristics that they desired (such as those things that contribute to higher grades), decide how to measure and analyze them (by using a PTQM checklist and scatter diagrams, for example), and then deciding on required improvements and a control process to “hold the gains.”

5. Outline how the DMAIC process might be used to improve a process in a school or university. What data or information might be difficult to obtain? Why?

Ans. One of the authors was actually involved in this type of process at both the program level and the course level. At that time, prior to the growing popularity of Six Sigma, he attempted with some success, to use TQ principles and tools in the course design process. In either design or improvement projects, the process should begin with problem definition and development of a list of customer needs and expectations (CTQ issues) as well as team formation in the Define stage, move on to Measurement of what is currently done and required metrics, Analysis is required to determine where improvements might be made,

investigation of possible Improvements and whether they solve the perceived problem, and ending with Control of the new process so that what the customer sees and believes the quality of the product to be (perceived quality) will be continually delivered. It must be expected that certain metrics will be difficult to find and may have to be created. Also, information relating to personnel may be restricted, due to confidentiality.

6. In a true story related by our colleague Professor James W. Dean, Jr., the general manager of an elevator company was frustrated with the lack of cooperation between the mechanical engineers who designed new elevators and the manufacturing engineers who determined how to produce them. The mechanical engineers would often completely design a new elevator without consulting with the manufacturing engineers, and then expect the factory to somehow figure out how to build it. Often the new products were difficult or nearly impossible to build, and their quality and cost suffered as a result. The designs were sent back to the mechanical engineers (often more than once) for engineering changes to improve their manufacturability, and customers sometimes waited for months for deliveries. The general manager believed that if the two groups of engineers would communicate early in the design process, many of the problems would be solved. At his wits' end, he found a large empty room in the plant and had both groups moved into it. The manager relaxed a bit, but a few weeks later he returned to a surprise. The two groups of engineers had finally learned to cooperate—by building a wall of bookcases and file cabinets right down the middle of the room, separating them from each other! What would you do in this situation? Relate this to Six Sigma and systems thinking.

Ans. Traditionally, there have been high "walls" built between design engineers and manufacturing engineers, so the Dean story is surprising, but not unbelievable. In fact, in many companies, there is a saying that Design develops the product requirements and "throws the new design over the wall" for Manufacturing to make. The implication is that neither side has wanted to talk to, or cooperate with, the other. Quality assurance personnel may be able to "bridge the gap" or "tear down the walls" between these groups by focusing on the needs of the organization to design a product with the customer in mind, where the customer can be seen as the immediate group (Manufacturing) by the design engineers, as well as the ultimate customers or consumers of the finished product. The Six Sigma approach would suggest that the areas need to have some common training on problem-solving approaches, while systems thinking would require that they explore the interactions between functions and the "client-customer" relationships that they have or wish to have.

7. Discuss some examples of "waste" in your life? How might they be avoided through lean thinking?

Ans. Answers will vary, depending on the student's definition of "waste." Often the definition will revolve around waste of time and money, the two things that students seem to always have a limited amount of (or think that they do). Many students will waste time playing video games. Others waste time due to poor study habits. Some students waste money on gambling. Others waste money by making unnecessary purchases, such as

spending too much for cellphone use. Lean thinking is sometimes defined as “getting more done with less,” which could be applied to all of these cases. To break the habit of excessive video gaming, the student must set priorities and plan to use time more efficiently. Setting a goal to limit game playing to a certain amount of time per day, with a control chart used to plot actual time spent, could reduce this waste substantially. Poor study habits lead to too much (or too little) time being applied to each subject. This could be improved by applying the 5-S’s to the study location, arranging computers, books, and other materials to be close at hand, etc. A goal of not spending more than x number of minutes on a difficult problem often results in more efficient use of time. Continuous improvement over time is a worthy objective for reducing all types of personal waste.

8. The Six Sigma philosophy seeks to develop technical leadership through extensive training, then use it in team-based projects designed to improve processes. To what extent are these two concepts (technical experts versus team experts) at odds? What must be done to prevent them from blocking success in improvement projects?

Ans. Ideally, the skills of technical experts (green or black Belts) will complement those of team members (often called subject matter experts, or SME’s). The two types of experts may be at odds if they cannot agree ways to analyze problems, what their measures show, and how to implement improvements and hold the gains through appropriate control techniques. To prevent them from clashing in such a way as to harm the results of the Six Sigma process, it is useful to see that each has training and/or orientation to the environmental factors, methods, and concepts used by the others. Also, the project champion has responsibility to see that any disputes are mediated and resolved in such a way as to enhance project success.

9. Discuss the following questions related to the case study *Applying Lean Six Sigma in a Financial Services Firm* in the text:
- How was the lean effort at the financial services firm structured organizationally?
 - What role did the kaizen event play in improving the way that the project was structured?
 - After the team had narrowed the focus to nine “quick hit” projects, what were the most significant results (outlined for four of the projects)? Which lean tools may/could have been used in order to realize these results?

Ans.

- The first step was forming a cross-functional team comprised of fund accounting, quality, and the central operations employees.
- The kaizen event, identified 30 possible improvement items and ranked them based on impact (high vs. low) and ease of implementation (easy vs. difficult). The projects were divided into two categories: quick-hit projects that they could realistically solve and implement within 90 days, and longer, strategic infrastructure improvements that required additional time to address. The team quickly recognized that longer-term

strategic projects— improving error tracking, creating a capacity model, and developing a project management process—were necessary to answer the fundamental questions. Actively measuring these errors would allow managers to quickly identify process steps that present high levels of risk. The capacity model would help define utilization rates for each fund accountant and team. Ultimately, the project management process will ensure a robust process for getting everyone involved in process improvement. Finally, nine quick hit projects were selected from the original list of 30. The projects were divided among the original five team members, and subject-matter experts and information technology resources were assigned to each project.

- c. The most significant results from the four projects included:
1. Eliminating line-by-line comparison of pre- and post-trial balances. In the past, this had been, a time-consuming, high-risk process. The improvement team developed a new value to be calculated on the pre- and post-trial balances to allow a quick comparison, thus eliminating the need for line-by-line reviews.
 2. Simplifying the corporate action (CA) review process. This process had been cumbersome, relied too much on people to catch discrepancies, and entailed four inspection and sign-off points were needed to ensure quality of information. The team developed a new daily automated report to compare the required values from the system to a secondary source, highlighting any discrepancies. Since its implementation there have been zero errors in the application of CA and a daily time savings of four hours.
 3. Creating an automatic feed of expense payments. The team redesigned the process to automatically feed the expense information from the original source on a daily basis, thus eliminating the need for distribution, entry, and verification steps.
 4. Eliminating manual price change sheets. This had been a time-consuming, manual process which introduced the possibility of data entry errors and miscalculations. The improvement team redesigned and automated the report to replace the manual process. Now a percent NAV change report is generated daily, thus reducing or eliminating miscalculations and rework.

It is easy to hypothesize where lean tools may/could have contributed to process improvements. These include:

- 5 S's – used to define a system for workplace organization and standardization.
- *Efficient layout and standardized work*. The layout of equipment and processes is designed according to the best operational sequence, by physically linking and arranging machines and process steps most efficiently, often in a cellular arrangement. Standardizing the individual tasks by clearly specifying the proper method reduces wasted human movement and energy.
- *Pull production*. In this system (also known as *kanban* or *just-in-time*), upstream suppliers do not produce until the downstream customer signals a need for parts.
- *Single minute exchange of dies (SMED)*. Reducing setup time adds value to the operation and facilitates smoother production flow.

- *Source inspection.* Inspection and control by process operators guarantees that product passed on to the next production stage conforms to specifications.
- *Continuous improvement.* All of the projects could be seen as falling under this category of continuous improvement.

10. Discuss the following questions related to the INFICON Six Sigma in Practice vignette:

- What role did training play in their application of lean Six Sigma methods to their operations?
- How did INFICON use the 5S lean Six Sigma tools in order to improve space utilization, manufacturing efficiencies, problem solving, and their competitiveness?

Ans.

a. Training played a vital part in implementing a 5S program at INFICON. The consulting group, CNYTDO, provided requisite coursework and helped identify projects for 6 company employees to become Six Sigma Black Belts. At the same time, CNYTDO provided basic training in Lean Six Sigma and Lean to a majority of the company. Individuals across all product families were trained in the four-step methodology of TWI Job Instruction (JI).

b. These individuals were placed into teams that were tasked with developing breakdowns of jobs that needed to be trained. By developing a workforce knowledgeable in Lean Six Sigma supported by the standardized training methodology of TWI, INFICON began to incorporate both the saving in efficiencies and floor space that Lean and Lean Six Sigma promised. The initiatives resulted in reducing cycle time by 25%, floor space from 15% to 30%, and rework by 12%.

COMMENTS ON THINGS TO DO

- Write down *your* process for preparing for an exam. How could this process be improved to make it shorter and/or more effective? Compare your process to those of your classmates. How might you collectively develop an improved process?

Comment: Answers will vary, depending on the exam preparation processes of the students. If several students develop a flow chart, then unnecessary delays and operations can be identified and discarded. Collectively, the students might then divide up, with half preparing for the next exam by using their “old” approach and half using a new “systematic” approach. They could then compare notes on time, learning, and grades, after the exam.

- Interview a manager at organization to identify the value-creation and support processes used. What techniques does the company use to improve them?

Comment: This exercise is designed to further students' awareness of the breadth of the "quality movement" and help them confirm how and whether the theory of quality is being applied in a practical settings in business and industry. As defined earlier, value-creation

processes (sometimes called *core processes*), are most important to “running the business” and maintaining or achieving a sustainable competitive advantage. Support processes, are those that contribute to the successful performance of an organization’s value-creation processes, employees, and daily operations, but do not directly add value to the product or service. Various improvement techniques are widely known among trained quality managers, but their use often depends on the size of the firm and the industry. Students may find that most companies are tracking some output measures that can be helpful in uncovering opportunities for error. Some Pareto charts and control charts may be found in many firms. Don’t expect to see cause-and-effect diagrams, scatter diagrams, correlation and regression, or experimental design, except in the most sophisticated quality-minded organizations (for example, those with a Six Sigma program).

3. Identify some examples of problems in each of the five problem-solving categories discussed in this chapter. Draw from your personal experiences.

Comment: The five problem-solving categories include: a) *conformance problems*, b) *efficiency problems*, c) *unstructured performance problems*, d) *product design problems*, and e) *process design problems*. Students may provide examples similar to the ones found in the text, such as:

1. *Conformance problems*, which are characterized by unsatisfactory performance that causes customer dissatisfaction, such as high levels of defects, service failures, or customer complaints. The processes that create these results are typically well-specified and can be easily described.
 2. *Efficiency problems*, which are characterized by unsatisfactory performance that causes dissatisfaction from the standpoint of noncustomer stakeholders, such as managers of financial or supply chain functions. Typical examples are high cost, excessive inventory, low productivity, and other process inefficiencies.
 3. *Unstructured performance problems*, which are characterized by unsatisfactory performance by processes that are not well-specified or understood. For example, a company might discover that employee turnover is much higher than desired or employee satisfaction is low. The factors that contribute to such results do not stem from processes that can easily be described.
 4. *Product design problems*, which involve designing new products or redesigning existing products to better satisfy customer needs.
 5. *Process design problems*, which involve designing new processes or substantially revising existing processes. These might include new factory processes to manufacture a new product line or designing a more flexible assembly line.
4. Three popular web sites for Six Sigma are <http://www.ge.com/sixsigma>, <http://www.isixsigma.com>, and <http://www.sixsigmaforum.com>. Explore these sites and classify information you can find there into the topical areas of the Six Sigma Body of Knowledge.

Comment: This project is designed to help the student to find how Six Sigma is viewed by various interested parties and reflected on their websites. Don't be surprised to see lack of agreement on topical areas that are suggested.

5. Devise a red-bead type of experiment using bags of M&M candies. Implement the experiment in class.

Comment: This project is designed to give students a hands-on feel for the concept of variability, as illustrated by this variation on W. Edwards Deming's experiment. If "defects" are defined as those colors which are rarely found in bags of M&M's, then the percentage of those colors will remain constant across many, many bags of the candy, no matter what the "skill level" of the workers are.

6. Set up and implement the funnel experiment using household items. Can you replicate the results discussed in this chapter?

Comment: Like the previous project, this project is designed to give students a hands-on feel for the concept of variability, as illustrated by this variation on W. Edwards Deming's experiment. In this case, the funnel will show that machine adjustments based on random observation of results is not generally effective, and is often counter-productive.

SOLUTIONS TO PROBLEMS

1. CablesplICE, Inc.'s manufacturing process consists of five steps: making conductors, adding insulation, adding sheathing, irradiation, and printing and coil cutting. Units are measured in meters. In 970,000 meters of cable, 700 defects were found in the conductors, and 75,000 defects were found in the insulation. In 440,000 meters of cable, 8930 defects were found in the sheathing, and no defects were found in the remaining two steps. a) Find DPU and the dpmo, and b) the sigma level for each process step.

Answer

- a. At CablesplICE, for the individual characteristics, we have:
 $DPU_{\text{conductors}} = 700/970000 = 0.000722$ defects per meter
 $DPU_{\text{insulation}} = 75000/970000 = 0.07732$ defects per meter
 $DPU_{\text{sheathing}} = 8930/440000 = 0.020295$ defects per meter
 $dpmo_{\text{conductors}} = (700/970000) \times 1000000 = 722$
 $dpmo_{\text{insulation}} = (75000/970000) \times 1000000 = 77,320$
 $dpmo_{\text{sheathing}} = (8930/440000) \times 1000000 = 20,295$
- b. To determine the sigma level, we use the equation: $NORM.S.INV(1 - dpmo/1000000) + 1.5$. Note that $dpmo/1000000$ is the same as DPU.

NORM.S.INV calculation in the Excel® spreadsheet, we get:

$$\text{NORM.S.INV}_{\text{conductors}} = (1 - 0.000722) + 1.5 = 4.69$$

$$\text{NORM.S.INV}_{\text{insulation}} = (1 - 0.07732) + 1.5 = 2.92$$

$$\text{NORM.S.INV}_{\text{sheathing}} = (1 - 0.020295) + 1.5 = 3.55$$

See spreadsheet Ch02-Solutions for computerized solutions.

2. For the CablesplICE's process, described in Problem 1, find the rolled throughput yield (RTY) for the five step process.

Answer

The RTY for the five steps in Cablecom's manufacturing process would be:

$$\text{RTY} = 0.999278 \times 0.922680 \times 0.979705 \times 1.0 \times 1.0 = 0.903302 \text{ or } 90.33\%$$

3. JW Famcor Company makes an artificial leather-like product for the fashion accessory market. The material is made in sheets and has the appearance of a thin rug. Each sheet is 36 inches wide and 100 feet long and is wound into a roll. The quality manager has requested that 100 rolls be inspected. Twenty seven non-conformances were found.
 - a. Calculate the nonconformances per unit (NPU) and the throughput yield.
 - b. If the production process consists of three steps, with step 1 having a TY of 93 percent; step 2; 89 percent, and step 3, 92 percent what is the rolled throughput yield (RTY), and the proportion nonconforming?

Answer

3. a. To calculate the NPU, use:

$$\text{NPU} = \text{Number of nonconformances found/number of units inspected} = 27/100 = 0.27$$

$$\text{TY} = e^{-\text{NPU}} = e^{-0.27} = 0.763 \text{ or } 76.3\% \text{ will be free from nonconformances.}$$

- b. The RTY for the three steps in the process would be:

$$\text{RTY} = 0.93 \times 0.89 \times 0.92 = 0.762 \text{ or } 76.2\% \text{ yield}$$

4. Miricelwell Insurance Company processes insurance policy applications in batches of 100. One day, they had 12 batches to process and after inspection, it was found that four batches had nonconforming policies. One batch had 3 nonconformances, another had 6, another had

2, and another had 1 nonconformance. What were (a) the proportion nonconforming for each batch, (b) the nonconformances per unit (NPU), in total for the 12 batches, and (c) the Total yield (TY) for the 12 batches?

Answer

4. 1) the proportion nonconforming for each batch, was 0.03, 0.06, 0.02, and 0.01
 2) the nonconformances per unit (NPU), in total for the 12 batches was:

$$\text{NPU} = (3 + 6 + 2 + 1) / (12 * 100) = 12 / 1200 = 0.01$$

 3) Total yield (TY) for the 10 batches = $\text{TY} = e^{-\text{NPU}} = e^{-0.01} = 0.99$ or 99.0% will be free from nonconformances, which agrees with the NPU figure, as well.
5. Tremblor Airlines measured their numbers of lost bags in one month and found that they had lost 150 bags for 10,000 customers. If the average number of bags per customer is 1.3, how many errors per million opportunities (epmo) does this represent? The worldwide rate of baggage mishandling reported by SITA (Société Internationale de Télécommunications Aéronautiques) in 2011 was 12.07 per 1,000 passengers. If the average number of checked bags per passenger is assumed to be 1.3, how many errors per million opportunities (epmo) does this represent? How does this compare with the rate for Tremblor – better or worse?

Answer

5. $\text{epmo} = (\text{Number of defects discovered}) / \text{opportunities for error} \times 1000000$
 Thus, a defect rate of 150 bags for 10,000 customers, if the average number of bags per customer is 1.3 is:

$$\text{epmo} = 150 / [(10,000)(1.3)] \times 1000000 = 11,538$$

 12.07 per 1,000 is equivalent to 12,070 dpmo if each passenger only had one bag.
 However, customers may have different numbers of bags; thus the number of opportunities for error must be based on the average number of bags per customer. If the average number of bags per customer is 1.3, and an airline recorded 12.07 lost bags for 1000 passengers in a month, then

$$\text{epmo} = 12.07 / [(1,000)(1.3)] \times 1000000 = 9,285$$

 The epmo number for Tremblor is somewhat worse than the SITA number.
6. Boardwork Electronics manufactures 250,000 circuit boards per month. A random sample of 4,000 boards is inspected every week for five characteristics. During a recent week, three defects were found for one characteristic, and two defects each were found for the other four characteristics. If these inspections produced defect counts that were

representative of the population, what are the dpmo's for the individual characteristics and what is the overall dpmo for the boards?

Answer

6. For the individual characteristics, we have:

$$\text{dpmo} = (3/4000) \times 1000000 = 7500 \text{ for the first characteristic}$$

$$\text{dpmo} = (2/4000) \times 1000000 = 500 \text{ each for the other four characteristics}$$

To calculate the overall dpmo, we have:

$$\text{dpmo} = (11/4000) \times 1000000/5 = 550$$

7. Megasigma Corp. has a process which they believe is operating near the six sigma level and want to verify this. If the specification for a critical part in the process is $2.75 \text{ cm} \pm 0.05$ and the standard deviation for the process is 0.02, at what sigma level is this process operating?

Answer:

If the specification limits for the process are $LSL = 2.70$ and $USL = 2.80$ and if the process standard deviation is 0.02, then using equation (2.4), we get:

$k \times \text{process standard deviation} = \text{tolerance}/2$, where k is the sigma level of:

$$k \times 0.02 = 0.1 / 2$$

$$k = 2.5$$

Conclusion: the process falls short of the three sigma level, thus it's far short of six sigma.

8. Newfound Fish Company advertises that 99.2% of their fish were caught within the past 36 hours and that all of their products are 100% fresh. How many dpmo does this claim represent? At what sigma level is this process operating?

Answer:

See spreadsheet Ch02-Solutions for computerized solutions.

The defect rate is $1.0 - .992 = 0.008$. Thus, $0.008 \times 1000000 = 8,000$ dpmo.

To determine the sigma level, we use the equation: $NORM.S.INV(1 - \text{dpmo}/1000000) + 1.5$.

Using the $NORM.S.INV$ calculation in the Excel® spreadsheet, we get:

$$NORM.S.INV_{\text{fish}} = (1 - 8,000/1000000) + 1.5 = 3.91, \text{ or just short of 4 sigma.}$$

9. During one month, MegaInvoice Company (MIC) processed 30,000 invoices for Alpha Corp, 19,000 for Beta Corp, and 15,000 for Gamma Corp. Of these, 300 of the Alpha, 323 of the Beta, and 285 of the Gamma invoices had to be reprocessed for errors. What is the overall defect rate and the sigma level for all of the combined batches? For each individual batch?

Answer:

See spreadsheet Ch02-Solutions for computerized solutions. To calculate the individual and combined dpmo's and sigma levels, we get:

| | Alpha | Beta | Gamma | Combined |
|-------------|-------|-------|-------|----------|
| Defect rate | 0.010 | 0.017 | 0.019 | 0.0142 |
| Sigma level | 3.826 | 3.620 | 3.575 | 3.692 |

Example individual calculation: Alpha Corp. defect rate = $(300/30000) = 0.010$.
 $NORM.S.INV(0.9900) + 1.5 = 3.826$ sigma
 Combined rate = $(300+323+285)/(30000+19000+15000) = 0.0142$. $NORM.S.INV(0.9858) + 1.5 = 3.692$ sigma

10. Expand Table 2.4 for sigma levels from 3.0 to 6.0 in increments of 0.2 on a spreadsheet. Assume a 1.5 sigma offset. Show dpmo on a chart as a function of the sigma level.

Answer:

We must use the relationship $dpmo = (1 - NORM.DIST(x,1.5,1,TRUE))*1000000$, where x is the sigma level. See spreadsheet Ch02-Solutions. We get:

| Sigma Level | dpmo | Sigma Level | dpmo |
|-------------|---------|-------------|-------|
| 3.0 | 66807.2 | 4.6 | 967.6 |
| 3.2 | 44565.5 | 4.8 | 483.4 |
| 3.4 | 28716.6 | 5.0 | 232.6 |
| 3.6 | 17864.4 | 5.2 | 107.8 |
| 3.8 | 10724.1 | 5.4 | 48.1 |
| 4.0 | 6209.7 | 5.6 | 20.7 |
| 4.2 | 3467.0 | 5.8 | 8.5 |
| 4.4 | 1865.8 | 6.0 | 3.4 |

11. Verasource Microprocessor Corporation (VMC) sells 2000 specialized computer processing chips each month at a price of \$1,500 each. Variable costs amount to \$1,500,000, and fixed costs are \$500,000. Currently the company has a defect rate of 8

percent (which are chips returned by customers, scrapped by VMC, and replaced). Note that the variable costs include the cost of producing the defective chips.

- a. What is the hidden cost to the company of making this rate of defectives instead of 2000 good chips each month?
- b. Suppose a Six Sigma effort can reduce the defects to a six sigma level (assume for simplicity that the defective rate is essentially zero). What is the impact on profitability?

Answer:

a) In order to produce and sell 2,000 good computer chips, VMC must start $2,000/0.92 = 2,174$ chips into production. However, since the variable cost of \$1,500,000 includes the cost of making scrap, the unit variable cost is therefore not $\$1,500,000/2,000 = \750 but $\$1,500,000/2,174 = \689.97 . Thus the price paid for poor quality, sometimes called the hidden factory, is $174 \times \$689.97 = \$120,060$. This additional cost is incurred to make useless products that can't be sold.

b) If a quality improvement initiative achieves a six sigma defect level, the defective rate is essentially zero. This will remove the variable cost of making the 174 defective units. The table below shows that the \$120,055 poor quality cost is eliminated from the variable costs, and the saved money falls to the bottom line to increase profits. Thus, the profit increased to \$1,120,060. The 8% reduction in operational costs produced a 12% increase in profit ($\$120060/\1000000).

Monthly Baseline

Monthly Six Sigma Results

| | |
|---|---|
| Sales: 2000 X \$1500.00 = 3000000 | Sales: 2000 X \$1500.00 = 3000000 |
| Variable Cost: 2174 X \$ 689.97 = 1500000 | Variable Cost: 2000 X \$ 689.97 = 1379940 |
| Contribution margin 1500000 | Contribution margin 1620060 |
| Fixed cost 500000 | Fixed cost 50000 |
| Net Profit 1000000 | Net Profit 1120060 |
| Profit margin 0.333 | Profit margin 0.373 |