As business organizations strive to maintain competitiveness in an ever-changing global economy, they are increasingly seeking new and better ways of operating. For some, this means changing from the traditional ways of operating to what is now referred to as lean operation. A **lean operation** is a flexible system of operation that uses considerably fewer resources (i.e., activities, people, inventory, and floor space) than a traditional system. Moreover, lean systems tend to achieve greater productivity, lower costs, shorter cycle times, and higher quality than nonlean systems.

Lean operation A flexible system that uses minimal resources and produces high-quality goods or services.

Lean systems are sometimes referred to as **just-in-time (JIT)** systems owing to their highly coordinated activities and delivery of goods that occur just as they are needed. The lean approach was pioneered by Toyota's founder, Taiichi Ohno, and Shigeo Shingo as a much faster and less costly way of producing automobiles. Following its success, today the lean approach is being applied in a wide range of manufacturing and service operations.

Just-in-time (JIT) A highly coordinated processing system in which goods move through the system, and services are performed, just as they are needed.

Lean is both a philosophy and a methodology that focuses on eliminating waste (non-value-added activities) and streamlining operations by closely coordinating all activities. Lean systems have three basic elements: They are demand driven, are focused on waste reduction, and have a culture that is dedicated to excellence and continuous improvement.

LO14.1 Explain the terms *lean operations* and *JIT*.

This chapter describes the lean production approach, including the basic elements of these systems and what it takes to make them work effectively. It also points out the benefits of these systems and the potential obstacles that companies may encounter when they attempt to convert from a traditional system to a lean production system.

14.1 INTRODUCTION

Lean operations began as lean manufacturing in the mid-1900s. It was developed by the Japanese automobile manufacturer Toyota. The development in Japan was influenced by the limited resources available at the time. Not surprisingly, the Japanese were very sensitive to waste and inefficiency. Widespread interest in lean manufacturing occurred after a book about automobile production, *The Machine That Changed the World,* by James Womack, Daniel Jones, and Daniel Roos, was published in 1990. As described in the book, Toyota's focus was on the elimination of all waste from every aspect of the process. Waste was defined as anything that interfered with, or did not add value to, the process of producing automobiles.

A stunning example of the potential of lean manufacturing was illustrated by the successful adoption of lean methods in the mid-1980s in a Fremont, California, auto plant. The plant was originally operated by General Motors (GM). However, GM closed the plant in 1982 because of its low productivity and high absenteeism. A few years later the plant was reopened as a joint venture of Toyota and GM, called NUMMI (New United Motor Manufacturing, Inc.). About 80 percent of the former plant workers were rehired, but the white-collar jobs were shifted from directing to supporting workers, and small teams were formed and trained to design, measure, and improve their performance. The result? By 1985 productivity and quality improved dramatically, exceeding all other GM plants, and absenteeism was negligible.

As other North American companies attempted to adopt the lean approach, they began to realize that in order to be successful, they needed to make major organizational and cultural changes. They also recognized that mass production, which emphasizes the efficiency of individual operations and leads to unbalanced systems and large inventories, was outmoded. Instead, they discovered that lean methods involve demand-based operations, flexible operations with rapid changeover capability, effective worker behaviors, and continuous improvement efforts.

Characteristics of Lean Systems

LO14.2 Describe the main characteristics of lean systems.

There are a number of characteristics that are commonly found in lean systems. An overview of these will provide a better understanding of lean systems.

Waste reduction—A hallmark of lean systems.

Continuous improvement—Another hallmark; never-ending efforts to improve.

Use of teams—Cross-functional teams, especially for process improvement.

Work cells—Along with cellular layouts allow for better communication and use of people.

Visual controls—Simple signals that enable efficient flow and quick assessment of operations.

High quality—In processes and in output.

Minimal inventory—Excess inventory is viewed as a waste.

Output only to match demand—Throughout the entire system; referred to a "demand pull."

Quick changeovers—Enables equipment flexibility and output variety without disruption.

Small lot sizes—Enables variety for batch production.

Lean culture—The entire organization embraces lean concepts and strives to achieve them.

Five principles embody the way lean systems function. Note the connections to the preceding characteristics.

LO14.3 List the five principles of the way lean systems function.

Identify customer values.

Focus on processes that create value.

Eliminate waste to create "flow".

Produce only according to customer demand.

Strive for perfection.

Benefits and Risks of Lean Systems

LO14.4 List some of the benefits and some of the risks of lean operation.

There are numerous benefits of lean systems, as well as some risks. The key benefits include:

Reduced waste due to emphasis on waste reduction.

Lower costs due to reduced waste and lower inventories.

Increased quality motivated by customer focus and the need for high-quality processes.

Reduced cycle time due to elimination of non-value-added operations.

Increased flexibility due to quick changeovers and small lot sizes.

Increased productivity due to elimination of non-value-added processes.

There are also certain risks that often accompany lean operations, such as:

Increased stress on workers due to increased responsibilities for equipment changeovers, problem solving, and process and quality improvement.

Fewer resources (e.g., inventory, people, time) available if problems occur.

Supply chain disruptions can halt operations due to minimal inventory or time buffers.

John Deere, the well-known tractor supply company, bolstered profits during a recession by using a JIT approach to reduce inventory levels. However, when demand picked up as the economy strengthened, a shortage of parts led to stretched-out delivery dates. Long lead times to replenish parts meant that in some cases harvesting equipment farmers wanted wouldn't be available until *after* harvest time! As a result, some farmers turned to Deere competitors to purchase needed equipment.

The Toyota Approach

LO14.5 Describe the Toyota Production System (TPS).

Many of the methods that are common to lean operations were developed as part of Japanese car maker Toyota's approach to manufacturing. Toyota's approach came to be known as the Toyota Production System (TPS), and it has served as a model for many implementations of lean systems, particularly in manufacturing. Many of the terms Toyota used are now commonly used in conjunction with lean operations, especially the following:

- **Muda:** Waste and inefficiency. Perhaps the driving philosophy. Waste and inefficiency can be minimized by using the following tactics.
- **Kanban:** A manual system used for controlling the movement of parts and materials that responds to *signals* of the need (i.e., demand) for delivery of parts or materials. This applies both to delivery to the factory and delivery to each workstation. The result is the delivery of a steady stream of containers of parts throughout the workday. Each container holds a small supply of parts or materials. New containers are delivered to replace empty containers.
- **Heijunka:** Variations in production volume lead to waste. The workload must be leveled; volume and variety must be averaged to achieve a steady flow of work.
- **Kaizen:** Continuous improvement of the system. There is always room for improvement, so this effort must be ongoing.
- **Jidoka:** Quality at the source. A machine automatically stops when it detects a bad part. A worker then stops the line. Also known as *autonomation.*

Muda Waste and inefficiency.

Kanban A manual system that signals the need for parts or materials.

Heijunka Workload leveling.

Kaizen Continuous improvement of the system.

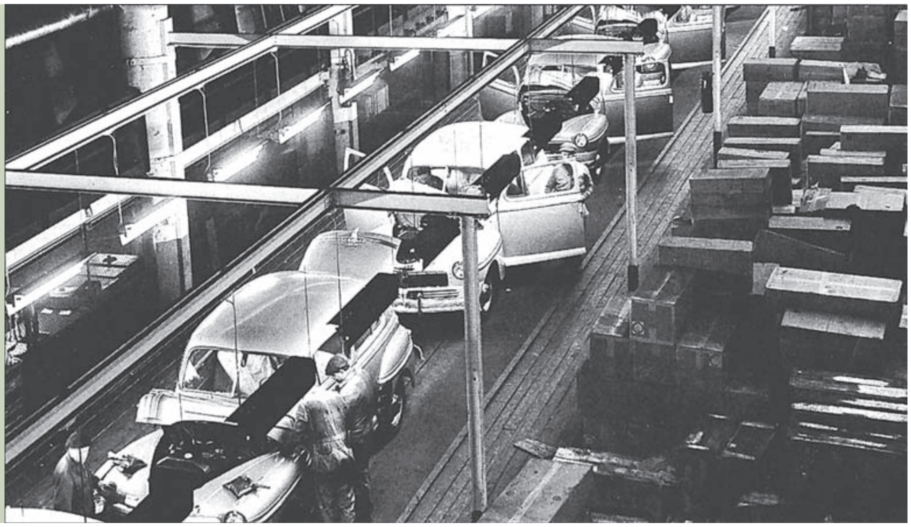
Jidoka Quality at the source (autonomation).

In some respects, the just-in-time concept was operational over 60 years ago at Henry Ford's great industrial complex in River Rouge, Michigan.

Toyota learned a great deal from studying Ford's operations and based its lean approach on what it saw. However, Toyota was able to accomplish something that Ford couldn't: a system that could handle some variety.

A widely held view of JIT/lean production is that it is simply a system for scheduling production that results in low levels of work-in-process and inventory. But in its truest sense, JIT/lean production represents a *philosophy* that encompasses every aspect of the

In the mid-1920s, the Ford assembly plant in River Rouge, Michigan, was a state-of-the-art industrial complex employing over 75,000 workers. In 1982, Eiji Toyoda, head of the Toyota Company, toasted Ford's then-president Philip Caldwell, saying, "There is no secret to how we learned to do what we do—we learned it at the Rouge."



Toyota Recalls

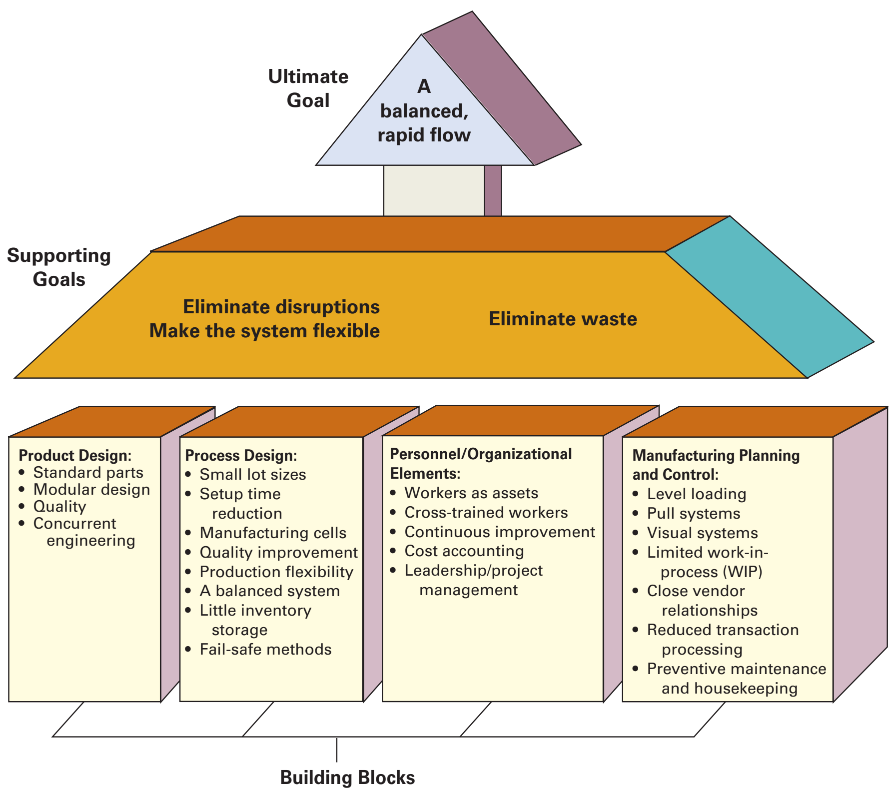
READING

In recent years Toyota has been plagued by more than a few recalls of its popular vehicles. This was somewhat surprising, given Toyota's reputation as a world leader in quality and lean production. Various news reports pointed to the following as possible causes: overdoing its quest for cost reduction; failure to heed early reports of problems and address them, possibly due to a refusal to admit there were problems; and increased difficulty in overseeing the entire system from Japan as overseas sales expanded.

FIGURE 14.1

An overview of the goals and building blocks of lean production systems

Source: Adapted from Thomas E. Vollmann, William L. Berry, and D. Clay Whybark, *Manufacturing Planning and Control Systems,* 5th ed. Copyright 2005 Irwin/McGraw-Hill Companies, Inc. Used with permission.



process, from design to after the sale of a product. The philosophy is to pursue a system that functions well with minimal levels of inventories, minimal waste, minimal space, and minimal transactions. Truly, a *lean* system. As such, it must be a system that is not prone to disruptions and is flexible in terms of the product variety and range of volume that it can handle.

In lean systems, quality is ingrained in both the product and the process. Companies that use lean operations have achieved a level of quality that enables them to function with small batch sizes and tight schedules. Lean systems have high reliability; major sources of inefficiency and disruption have been eliminated, and workers have been trained not only to function in the system but also to continuously improve it.

The ultimate goal of a lean operation is to achieve a system that matches supply to customer demand; supply is synchronized to meet customer demand in a smooth, uninterrupted flow. Figure 14.1 provides an overview of the goals and building blocks of a lean production system. The following pages provide more details about the supporting goals and building blocks.

14.2 SUPPORTING GOALS

The ultimate goal of lean is a *balanced* system, that is, one that achieves a smooth, rapid flow of materials and/or work through the system. The idea is to make the process time as short as possible by using resources in the best possible way. The degree to which the overall goal is achieved depends on how well certain supporting goals are achieved. Those goals are to

LO14.6 List the three goals of a lean system and explain the importance of each.

1. Eliminate disruptions.
2. Make the system flexible.
3. Eliminate waste, especially excess inventory.

Disruptions have a negative influence on the system by upsetting the smooth flow of products through the system, and they should be eliminated. Disruptions are caused by a variety of factors, such as poor quality, equipment breakdowns, changes to the schedule, and late deliveries. Quality problems are particularly disruptive because in lean systems there is no extra inventory that can be used to replace defective items. All disruptions should be eliminated where possible. This will reduce the uncertainty that the system must deal with.

A *flexible system* is one that is robust enough to handle a mix of products, often on a daily basis, and to handle changes in the level of output while still maintaining balance and throughput speed. This enables the system to deal with some uncertainty. Long setup times and long lead times negatively impact the flexibility of the system. Hence, reduction of setup and lead times is very important in a lean system.

Waste represents unproductive resources; eliminating waste can free up resources and enhance production. *Inventory* is an idle resource, taking up space and adding cost to the system. It should be minimized as much as possible. In the lean philosophy, there are eight wastes:

LO14.7 List the eight wastes according to lean philosophy.

1. **Excess inventory**—beyond minimal quantities, an idle resource takes up floor space and adds to cost.
2. **Overproduction**—involves excessive use of manufacturing resources.
3. **Waiting time**—requires space, adds no value.
4. **Unnecessary transporting**—increases handling, increases work-in-process inventory.
5. **Processing waste**—makes unnecessary production steps, scrap.
6. **Inefficient work methods**—reduce productivity, increase scrap, increase work-in-process inventory.
7. **Product defects**—require rework costs and possible lost sales due to customer dissatisfaction.
8. **Underused people**—relates to mental and creative abilities as well as physical abilities.

The existence of these wastes is an indication that improvement is possible. The list of wastes also can identify potential targets for continuous improvement efforts.

The kaizen philosophy for eliminating waste is based on the following tenets:[1]

1. Waste is the enemy, and to eliminate waste it is necessary to get the hands dirty.
2. Improvement should be done gradually and continuously; the goal is not big improvements done intermittently.
3. Everyone should be involved: top managers, middle managers, and workers.
4. Kaizen is built on a cheap strategy, and it does not require spending great sums on technology or consultants.
5. It can be applied anywhere.
6. It is supported by a visual system: a total transparency of procedures, processes, and values, making problems and wastes visible to all.
7. It focuses attention where value is created.
8. It is process oriented.
9. It stresses that the main effort of improvement should come from new thinking and a new work style.
10. The essence of organizational learning is to learn while doing.

14.3 BUILDING BLOCKS

LO14.8 Identify and briefly discuss the four building blocks of a lean production system.

The design and operation of a lean system provide the foundation for accomplishing the aforementioned goals. As shown in Figure 14.1, the building blocks are:

1. Product design.
2. Process design.
3. Personnel/organizational elements.
4. Manufacturing planning and control.

Speed and simplicity are two common threads that run through these building blocks.

Product Design

Four elements of product design are important for a lean production system:

1. Standard parts.
2. Modular design.
3. Highly capable production systems with quality built in.
4. Concurrent engineering.

The first two elements relate to speed and simplicity.

The use of *standard parts* means that workers have fewer parts to deal with, and training times and costs are reduced. Purchasing, handling, and checking quality are more routine and lend themselves to continual improvement. Another important benefit is the ability to use standard processing.

Modular design is an extension of standard parts. Modules are clusters of parts treated as a single unit. This greatly reduces the number of parts to deal with, simplifying assembly, purchasing, handling, training, and so on. Standardization has the added benefit of reducing the number of different parts contained in the bill of materials for various products, thereby simplifying the bill of materials.

[1]Adapted from Jorge Nascimento Rodrigues with Masaaki Imai, "Masaaki Imai: The Father of Kaizen," www.gurusonline.tv/uk/conteudos/imai.asp.

Lean requires highly capable production systems. Quality is the sine qua non ("without which not") of lean. It is crucial to lean systems because poor quality can create major disruptions. Quality must be embedded in goods and processes. The systems are geared to a smooth flow of work; the occurrence of problems due to poor quality creates disruption in this flow. Because of small lot sizes and the absence of buffer stock, production must cease when problems occur, and it cannot resume until the problems have been resolved. Obviously, shutting down an entire process is costly and cuts into planned output levels, so it becomes imperative to try to avoid shutdowns and to quickly resolve problems when they do appear.

Lean systems use a comprehensive approach to quality. Quality is designed into the product and the production process. High quality levels can occur because lean systems produce standardized products that lead to standardized job methods, employ workers who are very familiar with their jobs, and use standardized equipment. Moreover, the cost of product design quality (i.e., building quality in at the *design* stage) can be spread over many units, yielding a low cost per unit. It is also important to choose appropriate quality levels in terms of the final customer and of manufacturing capability. Thus, product design and process design must go hand in hand.

Engineering changes can be very disruptive to smooth operations. Concurrent engineering practices (described in Chapter 4) can substantially reduce these disruptions.

Process Design

Eight aspects of process design are particularly important for lean production systems:

1. Small lot sizes.
2. Setup time reduction.
3. Manufacturing cells.
4. Quality improvement.
5. Production flexibility.
6. A balanced system.
7. Little inventory storage.
8. Fail-safe methods.

Small Lot Sizes. In the lean philosophy, the ideal lot size is one unit, a quantity that may not always be realistic owing to practical considerations requiring minimum lot sizes (e.g., machines that process multiple items simultaneously, heat-treating equipment that processes multiple items simultaneously, and machines with very long setup times). Nevertheless, the goal is still to reduce the lot size as much as possible. Small lot sizes in both the production process and deliveries from suppliers yield a number of benefits that enable lean systems to operate effectively. First, with small lots moving through the system, in-process inventory is considerably less than it is with large lots. This reduces carrying costs, space requirements, and clutter in the workplace. Second, inspection and rework costs are less when problems with quality occur, because there are fewer items in a lot to inspect and rework.

Small lots also permit greater flexibility in scheduling. Repetitive systems typically produce a small variety of products. In traditional systems, this usually means long production runs of each product, one after the other. Although this spreads the setup cost for a run over many items, it also results in long cycles over the entire range of products. For instance, suppose a firm has three product versions, A, B, and C. In a traditional system, there would be a long run of version A (e.g., covering two or three days or more), then a long run of version B, followed by a long run of version C before the sequence would repeat. In contrast, a lean system, using small lots, would frequently shift from producing A to producing B and C. This flexibility enables lean systems to respond more quickly to changing customer demands for output: lean systems can produce just what is needed, when it is needed. The contrast between small and large lot sizes is illustrated in Figure 14.2. A summary of the benefits of small lot sizes is presented in Table 14.1.

FIGURE 14.2
Small versus large-lot run sizes

A = units of product A
B = units of product B
C = units of product C

Small-lot approach

AAA BBBBBBB CC AAA BBBBBBB CC AAA BBBBBBB CC AAA BBBBBBB CC

Time →

Large-lot approach

AAAAAAAAAAAA BBBBBBBBBBBBBBBBBBBBBBBBB CCCCCCCCC AAAAAAAAAAA

Time →

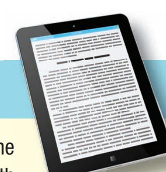
TABLE 4.1
Benefits of small lot sizes

Reduced inventory, lower carrying costs
Less space required to store inventory
Less rework if defects occur
Less inventory to "work off" before implementing product improvements
Increased visibility of problems
Increased production flexibility
Increased ease of balancing operations

It is important to note that the use of small lot sizes is not in conflict with the economic order quantity (EOQ) approach. Space is at a premium in Japan, making warehousing costs and the cost of space to store extra inventory near manufacturing very high. Also, on-site inventory increases the space between operations, which decreases communications, increases cycle time, and reduces visibility. All of these add to the burden of carrying inventory. So in an EOQ computation, using higher carrying cost, with carrying cost in the denominator, lot sizes naturally end up being smaller, and in some cases, much smaller.

Setup Time Reduction. Small lots and changing product mixes require frequent setups. Unless these are quick and relatively inexpensive, the time and cost to accomplish them can be prohibitive. Moreover, long setup times require holding more inventory than with short setup times. Hence, there is strong emphasis on reducing setup times. In JIT, workers are often trained to do their own setups. Moreover, programs to reduce setup time and cost are used to achieve the desired results; a deliberate effort is required, and workers are usually a valuable part of the process.

General Mills Turns to NASCAR to Reduce Changeover Time — READING



Karen Mills

MINNEAPOLIS—When General Mills wanted to cut the time it takes to make a product changeover at a Betty Crocker plant, it turned to NASCAR for help. The food company sent a team to work with a pit crew "because nobody can change over a car faster than these guys can," said Randy Darcy, senior vice president of General Mills' supply chain operations.

After studying the NASCAR crew, General Mills cut to 12 minutes—from as long as 412 hours—the time it takes to switch production lines from one Betty Crocker meal to another. One thing the mechanics learned from working with the NASCAR pit crew was to videotape each of the changeovers, then critique everything that happened.

Source: Excerpted from Karen Mills, "General Mills Looks Outside the Box for Innovation."

Single-minute exchange of die (SMED) A system for reducing changeover time.

Shigeo Shingo made a very significant contribution to lean operation with the development of what is called the **single-minute exchange of die (SMED)** system for reducing changeover time. It involves first categorizing changeover activities as either "internal" or "external" activities. Internal activities are those that can only be done while a machine is stopped (i.e., not running). Hence, they contribute to long changeover times. External activities are those that do not involve stopping the machine; they can be done before or after the changeover.

Hence, they do not affect changeover time. After activities have been categorized, a simple approach to achieving quick changeovers is to convert as many internal activities as possible to external activities and then streamline the remaining internal activities.

The potential benefits that can be achieved using the SMED system were impressively illustrated in 1982 at Toyota, when the changeover time for a machine was reduced from 100 minutes to 3 minutes! The principles of the SMED system can be applied to any changeover operation.

Setup tools and equipment and setup procedures must be simple and standardized. Multipurpose equipment or attachments can help to reduce setup time. For instance, a machine with multiple spindles that can easily be rotated into place for different job requirements can drastically reduce job changeover time. Moreover, *group technology* (described in Chapter 6) may be used to reduce setup cost and time by capitalizing on similarities in recurring operations. For instance, parts that are similar in shape, materials, and so on, may require very similar setups. Processing them in sequence on the same equipment can reduce the need to completely change a setup; only minor adjustment may be necessary.

Manufacturing Cells. One characteristic of lean production systems is multiple *manufacturing cells.* The cells contain the machines and tools needed to process families of parts having similar processing requirements. In essence, the cells are highly specialized and efficient production centers. Among the important benefits of manufacturing cells are reduced changeover times, high utilization of equipment, and ease of cross-training operators.

Quality Improvement. The occurrence of quality defects during the process can disrupt the orderly flow of work. Consequently, problem solving is important when defects occur. Moreover, there is a never-ending quest for *quality improvement,* which often focuses on finding and eliminating the causes of problems so they do not continually crop up.

Lean production systems sometimes minimize defects through the use of **autonomation** (note the extra syllable *on* in the middle of the word). Also referred to as *jidoka,* it involves the automatic detection of defects during production. It can be used with machines or manual operations. It consists of two mechanisms: one for detecting defects when they occur and another for a human stopping production to correct the cause of the defects. Thus, the halting of production forces immediate attention to the problem, after which an investigation of the problem is conducted, and corrective action is taken to resolve the problem.

Autonomation Automatic detection of defects during production.

A worker is assembling a Louis Vuitton handbag at the company's fine leather goods factory in the Normany town of Ducey in France. To keep its brand exclusive and contain costs, the company monitors growth and incorporates lean production processes.

TABLE 14.2
Guidelines for increasing production flexibility

1. Reduce downtime due to changeovers by reducing changeover time.
2. Use preventive maintenance on key equipment to reduce breakdowns and downtime.
3. Cross-train workers so they can help when bottlenecks occur or other workers are absent. Train workers to handle equipment adjustments and minor repairs.
4. Use many small units of capacity; many small cells make it easier to shift capacity temporarily and to add or subtract capacity than a few units of large capacity.
5. Use offline buffers. Store infrequently used safety stock away from the production area to decrease congestion and to avoid continually turning it over.
6. Reserve capacity for important customers.

Source: *Adapted from Edward M. Knod Jr. and Richard J. Schonberger, Operations Management: Meeting Customers' Demands, 7th ed. (New York: McGraw-Hill, 2001)*

Work Flexibility. The overall goal of a lean system is to achieve the ability to process a mix of products or services in a smooth flow. One potential obstacle to this goal is bottlenecks that occur when portions of the system become overloaded. The existence of bottlenecks reflects inflexibilities in a system. Process design can increase *production flexibility* and reduce bottlenecks in a variety of ways. Table 14.2 lists some of the techniques used for this purpose.

A Balanced System. Line balancing of production lines (i.e., distributing the workload evenly among workstations) helps to achieve a rapid flow of work through the system. Time needed for work assigned to each workstation must be less than or equal to the cycle time. The cycle time is set equal to what is referred to as the *takt time.* (*Takt* is the German word for musical meter.) ***Takt* time** is the cycle time needed in a production system to match the pace of production to the demand rate. It is sometimes said to be the heartbeat of a lean production system.

***Takt* time** The cycle time needed to match customer demand for final product.

Takt time is often set for a work shift. The procedure for obtaining the *takt* time is:

1. Determine the net time available per shift by subtracting any nonproductive time from total shift time.
2. If there is more than one shift per day, multiply the net time per shift by the number of shifts to obtain the net available time per day.
3. Compute *takt* time by dividing the net available time by demand.

EXAMPLE 1
excel
mhhe.com/stevenson12e

Given the following information, compute the *takt* time: Total time per shift is 480 minutes per day, and there are two shifts per day. There are two 20-minute rest breaks and a 30-minute lunch break per shift. Daily demand is 80 units.

SOLUTION

1. Compute net time available per shift:

Total time	480 minutes
Rest breaks	−40 minutes
Lunch	−30 minutes
	410 minutes per shift

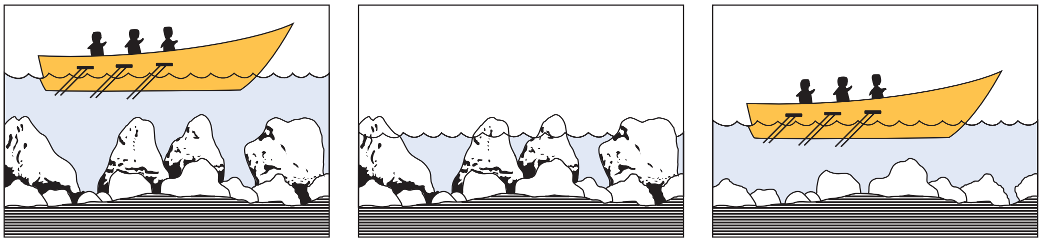
2. Compute the net time available per day:

410 minutes per shift
×2 shifts/day
820 minutes per day

3. Compute the *takt* time:

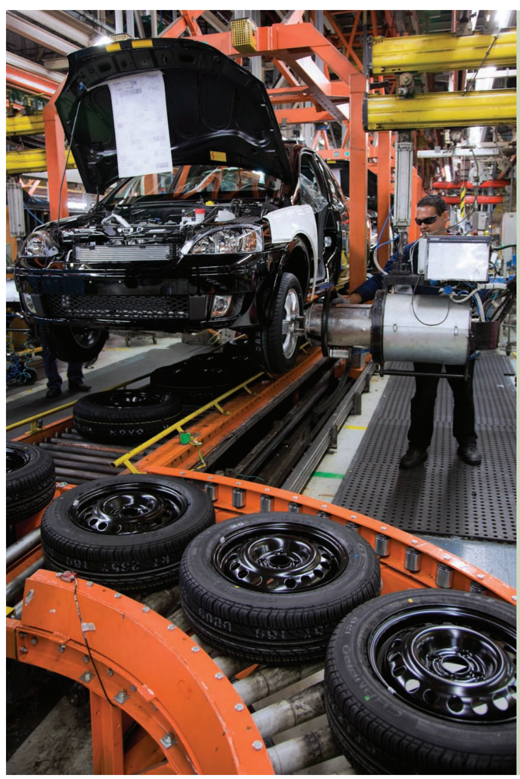
$$\textit{Takt}\text{ time} = \frac{\text{Net time available per day}}{\text{Daily demand}} = \frac{820\text{ minutes per day}}{80\text{ units per day}} \qquad (14\text{–}1)$$
$$= 10.25\text{ minutes per cycle}$$

FIGURE 14.3 Large rocks (problems) are hidden by a high water level (inventory) in A. Lower water level (B) reveals rocks (problems such as bottlenecks, waste, poor timing). Once the large rocks are removed, the water level (inventory) can be lowered (C). This process would be done repeatedly in the spirit of continuous improvement, achieving additional improvements with each iteration.



Once the *takt* time for the system has been determined, it can be used to determine the time that should be allotted to each workstation in the production process. Using the *takt* time results in minimizing work-in-process (WIP) inventory in instances where demand is stable and the system capacity matches demand. For unstable demand, additional inventory is needed to offset demand variability.

Inventory Storage. Lean systems are designed to *minimize* inventory storage. Recall that in the lean philosophy, inventory storage is a waste. Inventories are buffers that tend to cover up recurring problems that are never resolved, partly because they aren't obvious and partly because the presence of inventory makes them seem less serious. When a machine breaks down, it won't disrupt the system if there is a sufficient inventory of the machine's output to feed into the next workstation. The use of inventory as the "solution" can lead to increasing amounts of inventory if breakdowns increase. A better solution is to investigate the *causes* of machine breakdowns and focus on eliminating them. Similar problems with quality, unreliable vendors, and scheduling also can be solved by having ample inventories to fall back on. However, carrying all that extra inventory creates a tremendous burden in cost and space and allows problems to go unresolved.



A worker attaches wheels and hubcaps to a GM Montana Sport pick-up truck on an assembly line in Brazil.

The lean approach is to pare down inventories gradually in order to uncover the problems. Once they are uncovered and solved, the system removes more inventory, finds and solves additional problems, and so on. A useful analogy is a boat on a pond that has large, hidden rocks. (See Figure 14.3.) The rocks represent problems that can hinder production (the boat). The water in the pond that covers the rocks is the inventory in the system. As the water level is slowly lowered, the largest rocks are the first to appear (those problems are the first to be identified). At that point, efforts are undertaken to remove these rocks from the water (resolve these problems). Once that has been accomplished, additional water is removed from the pond, revealing the next layer of rocks, which are then worked on. As more rocks are removed, the need for water to cover them diminishes. Likewise, as more of the major production problems are solved, there is less need to rely on inventory or other buffers.

Low inventories are the result of a *process* of successful problem solving, one that has occurred over time. Furthermore, because it is unlikely that all problems will be found and resolved, it is necessary to be able to deal quickly with problems when they do occur. Hence, there is a continuing need to identify and solve problems within a short time span to prevent new problems from disrupting the smooth flow of work through the system.

One way to minimize inventory storage in a lean system is to have deliveries from suppliers go directly to the production floor, which completely eliminates the need to store incoming parts and materials. At the other end of the process, completed units are shipped out as soon as they are ready, which minimizes storage of finished goods. Coupled with low work-in-process inventory, these features result in systems that operate with very little inventory.

Among the advantages of lower inventory are less carrying cost, less space needed, less tendency to rely on buffers, less rework if defects occur, and less need to "work off" current inventory before implementing design improvements. But carrying less inventory also has some risks: The primary one is that if problems arise, there is no safety net. Another is missed opportunities if the system is unable to respond quickly to them.

Fail-Safe Methods. Failsafing refers to building safeguards into a process to reduce or eliminate the potential for errors during a process. The term that was used initially was *baka-yoke,* which meant "foolproofing." However, due to its offensive connotation, the term was changed to **poka-yoke,** which means "mistake proofing." Some examples of failsafing include an alarm that sounds if the weight of a packaged item is too low, indicating missing components; putting assembly components in "egg cartons" to ensure that no parts are left out; and designing parts that can only be attached in the correct position. There are several everyday examples in vehicles, including signals that warn that the key is still in the ignition if the car door is opened, warn if a door is ajar, warn if seatbelts are not fastened, or warn if the fuel level is low. Other examples include an ATM signal if a card is left in a machine, detectors at department stores that signal if a monitoring tag hasn't been removed from an item, electrical fuses and circuit breakers that interrupt electrical supply if a circuit is overloaded, computers and other devices that won't operate if an incorrect password is used, and so on. Much of the credit for poka-yoke thinking is attributed to the work of Shigeo Shingo, who extensively promoted the use of failsafing in operations.

Poka-yoke Safeguards built into a process to reduce the possibility of errors.

Personnel/Organizational Elements

There are five elements of personnel and organization that are particularly important for lean systems:

1. Workers as assets.
2. Cross-trained workers.
3. Continuous improvement.
4. Cost accounting.
5. Leadership/project management.

Workers as Assets. A fundamental tenet of the lean philosophy is that *workers are assets.* Well-trained and motivated workers are the heart of a lean system. They are given more authority to make decisions than their counterparts in more traditional systems, but they are also expected to do more.

"People" Firms Boost Profits, Study Shows — READING

Companies that treat employees as valuable assets, invest in training programs and use innovative workplace practices are more profitable than those that don't, a study found.

The two-year look at the workplace strategies of American companies was conducted by the management consulting firm Ernst & Young LLP for the Labor Department.

"This is a path-breaking study that shows the surest way to profits and productivity is to treat employees as assets to be developed rather than costs to be cut," Labor Secretary Robert Reich said at a press conference.

For the study, researchers at Harvard and Wharton business schools in partnership with the Ernst & Young Center for Business Innovation, reviewed over 100 papers examining business practices of thousands of U.S. companies.

The report focused on the economic benefits to companies of such Japanese-inspired concepts of labor-management cooperation as Just-In-Time inventory, which moves components to factories only as they are needed.

Among the findings:

- Economic benefits to companies were greatest when they successfully integrated innovations in management and technology with the appropriate employee training and "empowerment" programs.
- Companies investing in employee development enjoy significantly higher market values on average than their industry peers.
- Companies that were first among their competitors in implementing new management practices reaped the largest rewards.

According to the study, Motorola, Inc. estimates it earns $30 for every $1 invested in employee training, while Xerox Corp. found that in cooperation with its employee union it has reduced manufacturing costs by 30 percent and halved the time needed to develop new products.

Cross-Trained Workers. Workers are *cross-trained* to perform several parts of a process and operate a variety of machines. This adds to system flexibility because workers are able to help one another when bottlenecks occur or when a coworker is absent. It also helps line balancing.

Continuous Improvement. Workers in a lean system have greater responsibility for quality than workers in traditional systems, and they are expected to be involved in problem solving and *continuous improvement.* Lean system workers receive extensive training in statistical process control, quality improvement, and problem solving.

Problem solving is a cornerstone of any lean system. Of interest are problems that interrupt, or have the potential to interrupt, the smooth flow of work through the system. When such problems surface, it becomes important to resolve them quickly. This may entail increasing inventory levels *temporarily* while the problem is investigated, but the intent of problem solving is to eliminate the problem, or at least greatly reduce the chances of it recurring.

The Andon board in the GM Powertrain Engine facility is a visual communication tool. It advises employees of the real-time status of each machine within the manufacturing lines, enabling the production system to be run more effectively.

Andon System of lights used at each workstation to signal problems or slowdowns.

Problems that occur during production must be dealt with quickly. Some companies use a light system to signal problems; in Japan, such a system is called ***andon.*** Each workstation is equipped with a set of three lights. A green light means no problems, an amber light means a worker is falling a little bit behind, and a red light indicates a serious problem. The purpose of the light system is to keep others in the system informed and to enable workers and supervisors to immediately see when and where problems are occurring.

Japanese companies have been very successful in forming teams composed of workers and managers who routinely work on problems. Moreover, workers are encouraged to report problems and potential problems to the teams.

It is important that all levels of management actively support and become involved in problem solving. This includes a willingness to provide financial support and to recognize achievements. It is desirable to formulate goals with the help of workers, publicize the goals, and carefully document accomplishments. Goals give workers something tangible to strive for; recognition can help maintain worker interest and morale.

A central theme of a true lean approach is to work toward continual improvement of the system—reducing inventories, reducing setup cost and time, improving quality, increasing the output rate, and generally cutting waste and inefficiency. Toward that end, problem solving becomes a way of life—a "culture" that must be assimilated into the thinking of management and workers alike. It becomes a never-ending quest for improving operations as all members of the organization strive to improve the system.

One challenge to continuous improvement is that once the "easy" improvements have been made, it becomes more difficult to keep workers motivated to continue to look for further improvements.

Workers in lean systems have more stress than their counterparts in more traditional systems. Stress comes not only from their added authority and responsibility but also from the high-paced system they work in, where there is little slack and a continual push to improve.

Cost Accounting. Another feature of some lean systems is the method of allocating overhead. Traditional accounting methods sometimes distort overhead allocation because they allocate it on the basis of direct labor hours. However, that approach does not always accurately reflect the consumption of overhead by different jobs. In addition, the number of direct labor hours in some industries has declined significantly over the years and now frequently accounts for a relatively small portion of the total cost. Conversely, other costs now represent a major portion of the total cost. Therefore, labor-intensive jobs (i.e., those that use relatively large proportions of direct labor) may be assigned a disproportionate share of overhead, one that does not truly reflect actual costs. That in turn can cause managers to make poor decisions. Furthermore, the need to track direct labor hours can itself involve considerable effort.

Activity-based costing Allocation of overhead to specific jobs based on their percentage of activities.

One alternative method of allocating overhead is **activity-based costing.** This method is designed to more closely reflect the actual amount of overhead consumed by a particular job or activity. Activity-based costing first identifies traceable costs and then assigns those costs to various types of activities such as machine setups, inspection, machine hours, direct labor hours, and movement of materials. Specific jobs are then assigned overhead based on the percentage of activities they consume.

Leadership/Project Management. Another feature of lean systems relates to *leadership.* Managers are expected to be leaders and facilitators, not order givers. Lean encourages two-way communication between workers and managers.

Manufacturing Planning and Control

Seven elements of manufacturing planning and control are particularly important for lean systems:

1. Level loading.
2. Pull systems.
3. Visual systems.

4. Limited work-in-process (WIP).
5. Close vendor relationships.
6. Reduced transaction processing.
7. Preventive maintenance and housekeeping.

Level Loading. Lean systems place a strong emphasis on achieving stable, level daily mix schedules. Toward that end, the master production schedule is developed to provide *level capacity loading*. That may entail a rate-based production schedule instead of the more familiar quantity-based schedule. Moreover, once established, production schedules are relatively fixed over a short time horizon, and this provides certainty to the system. Even so, some adjustments may be needed in day-to-day schedules to achieve level capacity requirements. Suppliers like level loading because it means smooth demand for them.

A level production schedule requires smooth production. When a company produces different products or product models, it is desirable to produce in small lots (to minimize work-in-process inventory and to maintain flexibility) and to spread the production of the different products throughout the day to achieve smooth production. The extreme case would be to produce one unit of one product, then one of another, then one of another, and so on. While this approach would allow for maximum smoothness, it would generally not be practical because it would generate excessive setup costs.

Mixed-model sequencing begins with daily production requirements of each product or model. For instance, suppose a department produces three models, A, B, and C, with these daily requirements:

Three issues then need to be resolved. One is which sequence to use (C-B-A, A-C-B, etc.), another is how many times (i.e., cycles) the sequence should be repeated daily, and the third is how many units of each model to produce in each cycle.

Model	Daily Quantity
A	10
B	15
C	5

The choice of sequence can depend on several factors, but the key one is usually the setup time or cost, which may vary depending on the sequence used. For instance, if two of the models, say A and C, are quite similar, the sequences A-C and C-A may involve only minimal setup changes, whereas the setup for model B may be more extensive. Choosing a sequence that has A-C or C-A will result in about 20 percent fewer setups over time than having B produced between A and C on every cycle.

The number of cycles per day depends on the daily production quantities. If every model is to be produced in every cycle, which is often the goal, determining the smallest integer that can be evenly divided into each model's daily quantity will indicate the number of cycles. This will be the fewest number of cycles that will contain one unit of the model with the lowest quantity requirements. For models A, B, and C shown in the preceding table, there should be five cycles (5 can be evenly divided into each quantity). High setup costs may cause a manager to use fewer cycles, trading off savings in setup costs and level production. If dividing by the smallest daily quantity does not yield an integer value for each model, a manager may opt for using the smallest production quantity to select a number of cycles, but then produce more of some items in some cycles to make up the difference.

Sometimes a manager determines the number of units of each model in each cycle by dividing each model's daily production quantity by the number of cycles. Using five cycles per day would yield the following:

Model	Daily Quantity	Units per Cycle
A	10	10/5 = 2
B	15	15/5 = 3
C	5	5/5 = 1

These quantities may be unworkable due to restrictions on lot sizes. For example, model B may be packed four to a carton, so producing three units per cycle would mean that at times finished units (inventory) would have to wait until sufficient quantities were available to fill a crate. Similarly, there may be standard production lot sizes for some operations. A heat-treating process might involve a furnace that can handle six units at a time. If the different models require different furnace temperatures, they could not be grouped. What would be necessary here is an analysis of the trade-off between furnace lot size and the advantages of level production.

EXAMPLE 2

Determine a production plan for these three models using the sequence A-B-C:

Model	Daily Quantity
A	7
B	16
C	5

SOLUTION

The smallest daily quantity is 5, but dividing the other two quantities by 5 does not yield integers. The manager might still decide to use five cycles. Producing one unit of models A and C and three units of model B in each of the five cycles would leave the manager short two units of model A and one unit of model B. The manager might decide to intersperse those units like this to achieve nearly level production:

Cycle	1	2	3	4	5
Pattern	A B(3) C	A(2) B(3) C	A B(4) C	A(2) B(3) C	A B(3) C
Extra unit(s)		A	B	A	

If the requirement for model A had been 8 units a day instead of 7, the manager might decide to use the following pattern:

Cycle	1	2	3	4	5
Pattern	A(2) B(3) C	A B(3) C	A(2) B(4) C	A B(3) C	A(2) B(3) C
Extra unit(s)	A		A B		A

Push system Work is pushed to the next station as it is completed.

Pull system A workstation pulls output from the preceding station as it is needed.

Pull Systems. The terms *push* and *pull* are used to describe two different systems for moving work through a production process. In traditional production environments, a **push system** is used: When work is finished at a workstation, the output is *pushed* to the next station; or, in the case of the final operation, it is pushed on to final inventory. Conversely, in a **pull system,** control of moving the work rests with the following operation; each workstation *pulls* the output from the preceding station as it is needed; output of the final operation is pulled by customer demand or the master schedule. Thus, in a pull system, work moves on in response to demand from the next stage in the process, whereas in a push system, work moves on as it is completed, without regard to the next station's readiness for the work. Consequently, work may pile up at workstations that fall behind schedule because of equipment failure or the detection of a problem with quality.

Communication moves backward through the system from station to station. Each workstation (i.e., customer) communicates its need for more work to the preceding workstation (i.e., supplier), thereby assuring that supply equals demand. Work moves "just in time" for the next operation; the flow of work is thereby coordinated, and the accumulation of excessive inventories between operations is avoided. Of course, some inventory is usually present because operations are not instantaneous. If a workstation waited until it received a request from the next workstation before starting its work, the next station would have to wait for the preceding station to perform its work. Therefore, by design, each workstation produces just enough output to meet the (anticipated) demand of the next station. This can be accomplished by having the succeeding workstation communicate its need for input sufficiently ahead of time to allow the preceding station to do the work. Or there can be a small buffer of stock between stations; when the buffer decreases to a certain level, this signals the preceding station to produce enough output to replenish the buffer supply. The size of the buffer supply depends on the cycle time at the preceding workstation. If the cycle time is short, the station will need little or no buffer; if the cycle time is long, it will need a considerable amount of buffer. However, production occurs only in response to *usage* of the succeeding station; work is still pulled by the demand generated by the next operation.

Pull systems aren't necessarily appropriate for all manufacturing operations because they require a fairly steady flow of repetitive work. Large variations in volume, product mix, or product design will undermine the system.

Visual Systems. In a pull system work flow is dictated by "next-step demand." A system can communicate such demand in a variety of ways, including a shout or a wave, but by far the most commonly used device is the **kanban** card. *Kanban* is a Japanese word meaning "signal" or "visible record." When a worker needs materials or work from the preceding station, he or she uses a kanban card. In effect, the kanban card is the *authorization* to move or work on parts. In kanban systems, no part or lot can be moved or worked on without one of these cards.

Kanban Card or other device that communicates demand for work or materials from the preceding station.

There are two main types of kanbans:

1. **Production kanban (p-kanban):** signals the need to produce parts.
2. **Conveyance kanban (c-kanban):** signals the need to deliver parts to the next work center.

The system works this way: A kanban card is affixed to each container. When a workstation needs to replenish its supply of parts, a worker goes to the area where these parts are stored and withdraws one container of parts. Each container holds a predetermined quantity. The worker removes the kanban card from the container and posts it in a designated spot

At TriState Industries, a kanban system is in effect to move work through the production system. Shown here, a kanban card provides the authorization to move or work on parts.

Special carts were designed that, when filled, act as a visual signal that they are ready to be moved to the next work cell. An empty cart indicates that it is time to produce, in order to refill the cart.

where it will be clearly visible, and the worker moves the container to the workstation. The posted kanban is then picked up by a stock person who replenishes the stock with another container, and so on down the line. Demand for parts triggers a replenishment, and parts are supplied as usage dictates. Similar withdrawals and replenishments—all controlled by kanbans—occur all the way up and down the line from vendors to finished-goods inventories. If supervisors decide the system is too loose because inventories are building up, they may decide to tighten the system and withdraw some kanbans. Conversely, if the system seems too tight, they may introduce additional kanbans to bring the system into balance. Vendors also can influence the number of containers. Moreover, trip times can affect the number: Longer trip times may lead to fewer but larger containers, while shorter trip times may involve a greater number of small containers.

It is apparent that the number of kanban cards in use is an important variable. One can compute the ideal number of kanban cards using this formula:

$$N = \frac{DT(1 + X)}{C} \qquad (14\text{–}2)$$

where

N = Total number of containers (1 card per container)

D = Planned usage rate of using work center

T = Average waiting time for replenishment of parts plus average production time for a container of parts

X = Policy variable set by management that reflects possible inefficiency in the system (the closer to 0, the more efficient the system)

C = Capacity of a standard container (should be no more than 10 percent of daily usage of the part)

Note that D and T must use the same units (e.g., minutes, days).

EXAMPLE 3

Usage at a work center is 300 parts per day, and a standard container holds 25 parts. It takes an average of .12 day for a container to complete a circuit from the time a kanban card is received until the container is returned empty. Compute the number of kanban cards (containers) needed if $X = .20$.

SOLUTION

$N = ?$

$D = 300$ parts per day

$T = .12$ day

$C = 25$ parts per container

$X = .20$

$$N = \frac{300(.12)(1 + .20)}{25} = 1.728; \text{ round to 2 containers}$$

Note: Rounding up will cause the system to be looser, and rounding down will cause it to be tighter. Usually, rounding up is used.

Although the goals of MRP and kanban are essentially the same (i.e., to improve customer service, reduce inventories, and increase productivity), their approaches are different. Neither MRP nor kanban is a stand-alone system—each exists within a larger framework. MRP is a computerized system; kanban is a manual system that may be part of a lean system, although lean can exist without kanban.

Kanban is essentially a two-bin type of inventory: Supplies are replenished semiautomatically when they reach a predetermined level. MRP is more concerned with projecting requirements and with planning and scheduling operations.

A major benefit of the kanban system is its simplicity; a major benefit of MRP is its ability to handle complex planning and scheduling. In addition, MRP II enables management to answer what-if questions for capacity planning.

The philosophies that underlie kanban systems are quite different from those traditionally held by manufacturers. Nonetheless, both approaches have their merits, so it probably would not make sense in most instances to switch from one method of operation to the other. Moreover, to do so would require a tremendous effort. It is noteworthy that at the same time that Western manufacturers are studying kanban systems, some Japanese manufacturers are studying MRP systems. This suggests the possibility that either system could be improved by incorporating selected elements of the other. That would take careful analysis to determine which elements to incorporate as well as careful implementation of selected elements, and close monitoring to assure that intended results were achieved.

Whether manufacturers should adopt the kanban method is debatable. Some form of it may be useful, but kanban is merely an information system; by itself it offers little in terms of helping manufacturers become more competitive or productive. By the same token, MRP alone will not achieve those results either. Instead, it is the overall approach to manufacturing that is crucial; it is the commitment and support of top management and the continuing efforts of all levels of management to find new ways to improve their manufacturing planning and control techniques, and to adapt those techniques to fit their particular circumstances, that will determine the degree of success.

Comment The use of either kanban or MRP does not preclude the use of the other. In fact, it is not unusual to find the two systems used in the same production facility. Some Japanese manufacturers, for example, are turning to MRP systems to help them plan production. Both approaches have their advantages and limitations. MRP systems provide the capability to explode the bill of materials to project timing and material requirements that can then be used to plan production. But the MRP assumption of fixed lead times and infinite capacity can often result in significant problems. At the shop floor level, the discipline of a kanban system, with materials pull, can be very effective. But kanban works best when there is a uniform flow through the shop; a variable flow requires buffers, and this reduces the advantage of a pull system.

In effect, some situations are more conducive to a visual approach, others to an MRP approach. Still others can benefit from a hybrid of the two. Hybrid systems like kanban/ MRP can be successful if MRP is used for planning and kanban is used as the execution system.

Limited Work-in-Process (WIP). Movement of materials and WIP in a lean system is carefully coordinated, so that they arrive at each step in a process just as they are needed. Controlling the amount of WIP in a production system can yield substantial benefits. One is lower carrying costs due to lower WIP inventory. Another is the increased flexibility that would be lost if there were large amounts of WIP in the system. In addition, low WIP aids scheduling and saves costs of rework and scrapping if there are design changes.

Controlling WIP also results in low cycle-time variability. WIP is determined by cycle time and the arrival rate of jobs. According to Little's law, WIP $=$ Cycle time $\times$ Arrival rate. If both WIP and the arrival rate of jobs are held constant, the cycle time will also be constant. In a push system, the arrival rate of jobs is not held constant, so there is the possibility of large WIP buildups, which results in high variability in cycle times. This forces companies to quote longer lead times to customers to allow for variable cycle times.

There are two general approaches to controlling WIP; one is kanban and the other is constant work-in-process (CONWIP). Kanban's control of WIP focuses on individual workstations, while CONWIP'S focus is on the system as a whole. With CONWIP, when a job exits the system, a new job is allowed to enter. This results in a constant level of work-in-process.

Kanban works best in an environment that is stable and predictable. CONWIP offers an advantage if there is variability in a line, perhaps due to a breakdown in an operation or a quality problem. With kanban, upstream work is blocked and processing will stop fairly quickly, while with CONWIP upstream stations can continue to operate for a somewhat longer time. Then, after the reason for stoppage has been corrected, there will be less need to make up lost production than if the entire line had been shut down, as it would be under kanban. Also, in a mixed product environment, CONWIP can be easier than kanban because kanban focuses on specific part numbers whereas CONWIP does not.

Close Vendor Relationships. Lean systems typically have *close relationships with vendors,* who are expected to provide frequent small deliveries of high-quality goods. Traditionally, buyers have assumed the role of monitoring the quality of purchased goods, inspecting shipments for quality and quantity, and returning poor-quality goods to the vendor for rework. JIT systems have little slack, so poor-quality goods cause a disruption in the smooth flow of work. Moreover, the inspection of incoming goods is viewed as inefficient because it does not add value to the product. For these reasons, the burden of ensuring quality shifts to the vendor. Buyers work with vendors to help them achieve the desired quality levels and to impress upon them the importance of consistent, high-quality goods. The ultimate goal of the buyer is to be able to *certify* a vendor as a producer of high-quality goods. The implication of certification is that a vendor can be relied on to deliver high-quality goods without the need for buyer inspection.

Suppliers also must be willing and able to ship in small lots on a regular basis. Ideally, suppliers themselves will be operating under JIT systems. Buyers can often help suppliers convert to JIT production based on their own experiences. In effect, the supplier becomes part of an extended JIT system that integrates the facilities of buyer and supplier. Integration is easier when a supplier is dedicated to only one or a few buyers. In practice, a supplier is likely to have many different buyers, some using traditional systems and others using JIT. Consequently, compromises may have to be made by both buyers and suppliers.

Traditionally, a spirit of cooperation between buyer and seller has not been present; buyers and vendors have had a somewhat adversarial relationship. Buyers have generally regarded price as a major determinant in sourcing, and they have typically used *multiple-source* purchasing, which means having a list of potential vendors and buying from several to avoid getting locked into a sole source. In this way, buyers play vendors off against each other to get better pricing arrangements or other concessions. The downside is that vendors cannot rely on a long-term relationship with a buyer, and they feel no loyalty to a particular buyer. Furthermore, vendors have often sought to protect themselves from losing a buyer by increasing the number of buyers they supply.

Under JIT purchasing, good vendor relationships are very important. Buyers take measures to reduce their lists of suppliers, concentrating on maintaining close working relationships with a few good ones. Because of the need for frequent, small deliveries, many buyers attempt to find local vendors to shorten the lead time for deliveries and to reduce lead time variability. An added advantage of having vendors nearby is quick response when problems arise.

JIT purchasing is enhanced by long-term relationships between buyers and vendors. Vendors are more willing to commit resources to the job of shipping according to a buyer's JIT system given a long-term relationship. Moreover, price often becomes secondary to other aspects of the relationship (e.g., consistent high quality, flexibility, frequent small deliveries, and quick response to problems).

Supplier Tiers A key feature of many lean production systems is the relatively small number of suppliers used. In traditional production, companies often deal with hundreds or even thousands of suppliers in a highly centralized arrangement not unlike a giant wheel with many spokes. The company is at the hub of the wheel, and the spokes radiate out to suppliers, each of whom must deal directly with the company. In traditional systems, a supplier does not know the other suppliers or what they are doing. Each supplier works to specifications provided by the buyer. Suppliers have very little basis (or motivation) for suggesting improvements. Moreover, as companies play one supplier off against others, the sharing of information is more risky than rewarding. In contrast, lean production companies may employ a tiered approach for suppliers: They use relatively few first-tier suppliers who work directly with the company or who supply major subassemblies. The first-tier suppliers are responsible for dealing with second-tier suppliers who provide components for the subassemblies, thereby relieving the final buyer from dealing with large numbers of suppliers.

The automotive industry provides a good example of this situation. Suppose a certain car model has an electric seat. The seat and motor together might entail 250 separate parts. A traditional producer might use more than 30 suppliers for the electric seat, but a lean producer might use a single (first-tier) supplier who has the responsibility for the entire seat unit. The company would provide specifications for the overall unit, but leave to the supplier the details of the motor, springs, and so on. The first-tier supplier, in turn, might subcontract the motor to a second-tier supplier, the track to another second-tier supplier, and the cushions and fabric to still another. The second-tier suppliers might subcontract some of their work to third-tier suppliers, and so on. Each tier has only to deal with those just above it or just below it. Suppliers on each level are encouraged to work with each other, and they are motivated to do so because that increases the probability that the resulting item (the seat) will meet or exceed the final buyer's expectations. In this "team of suppliers" approach, all suppliers benefit from a successful product, and each supplier bears full responsibility for the quality of its portion of the product. Figure 14.4 illustrates the difference between the traditional approach and the tiered approach.

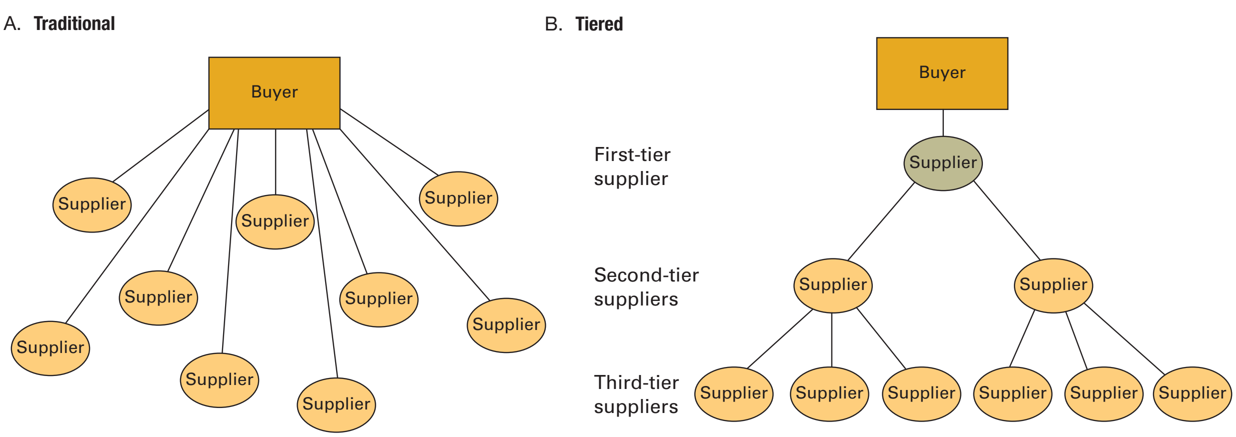
Reduced Transaction Processing. Traditional manufacturing systems often have many built-in transactions that do not add value. In their classic article, "The Hidden Factory,"[2] Jeffrey G. Miller and Thomas Vollmann identify a laundry list of transaction processing that comprises a "hidden factory" in traditional manufacturing planning and control systems, and point out the tremendous cost burden that results. The transactions can be classified as logistical, balancing, quality, or change transactions.

Logistical transactions include ordering, execution, and confirmation of materials transported from one location to another. Related costs cover shipping and receiving personnel, expediting orders, data entry, and data processing.

Balancing transactions include forecasting, production planning, production control, procurement, scheduling, and order processing. Associated costs relate to the personnel involved in these and supporting activities.

Quality transactions include determining and communicating specifications, monitoring, recording, and followup activities. Costs relate to appraisal, prevention, internal failures (e.g., scrap, rework, retesting, delays, administration activities) and external failures (e.g., warranty costs, product liability, returns, potential loss of future business).

FIGURE 14.4 Traditional supplier network compared to supplier tiers



[2]Excerpted from Jeffrey Miller and Thomas Vollmann, "The Hidden Factory," *Harvard Business Review,* September/October 1985, pp. 141–50.

Change transactions primarily involve engineering changes and the ensuing changes generated in specifications, bills of material, scheduling, processing instructions, and so on. Engineering changes are among the most costly of all transactions.

Lean systems cut transaction costs by reducing the number and frequency of transactions. For example, suppliers deliver goods directly to the production floor, bypassing the storeroom entirely, thereby avoiding the transactions related to receiving the shipment into inventory storage and later moving the materials to the production floor. In addition, vendors are certified for quality, eliminating the need to inspect incoming shipments for quality. The unending quest for quality improvement that pervades lean systems eliminates many of the above-mentioned quality transactions and their related costs. The use of bar coding (not exclusive to lean systems) can reduce data entry transactions and increase data accuracy.

Preventive Maintenance and Housekeeping. Because lean systems have very little in-process inventory, equipment breakdowns can be extremely disruptive. To minimize breakdowns, companies use **preventive maintenance** programs, which emphasize maintaining equipment in good operating condition and replacing parts that have a tendency to fail before they fail. Workers are often responsible for maintaining their own equipment.

Preventive maintenance Maintaining equipment in good operating condition and replacing parts that have a tendency to fail before they actually do fail.

Even with preventive maintenance, occasional equipment failures will occur. Companies must be prepared for this, so they can quickly return equipment to working order. This may mean maintaining supplies of critical spare parts and making other provisions for emergency situations, perhaps maintaining a small force of repair people or training workers to do certain repairs themselves. Note that when breakdowns do occur, they indicate potential opportunities to be exploited in a lean environment.

Housekeeping Maintaining a workplace that is clean and free of unnecessary materials.

Housekeeping involves keeping the workplace clean as well as keeping it free of any materials that are not needed for production, because those materials take up space and may cause disruptions to the work flow.

Housekeeping is part of what is often referred to as the five S's, which are five behaviors intended to make the workplace effective:

1. **Sort.** Decide which items are needed to accomplish the work, and keep only those items.
2. **Straighten.** Organize the workplace so that the needed items can be accessed quickly and easily.
3. **Sweep.** Keep the workplace clean and ready for work. Perform equipment maintenance regularly.
4. **Standardize.** Use standard instructions and procedures for all work.
5. **Self-discipline.** Make sure that employees understand the need for an uncluttered workplace.

Among the benefits of the five S's are increased productivity, improved employee morale, decreased risk of accidents, and improved appearance for visitors. Employees and managers must appreciate the rationale for the five S's. Otherwise, they may view them as unnecessary and a waste of effort.

Lean systems have been described and compared with traditional manufacturing systems in the preceding pages. Table 14.3 provides a brief overview of those comparisons.

TABLE 4.3
Comparison of lean and traditional production philosophies

Factor	Traditional	Lean
Inventory	Much, to offset forecast errors, late deliveries	Minimal necessary to operate
Deliveries	Few, large	Many, small
Lot sizes	Large	Small
Setups, runs	Few, long runs	Many, short runs
Vendors	Long-term relationships are unusual	Partners
Workers	Necessary to do the work	Assets

14.4 LEAN TOOLS

LO14.9 Describe key lean improvement tools.

This section describes several tools that are used for process improvement in lean systems.

Value Stream Mapping

Value stream mapping A visual tool to systematically examine the flow of materials and information.

Value stream mapping is a visual tool to systematically examine the flow of materials and information involved in bringing a product or service to a consumer. The technique originated at Toyota, where it is referred to as "Material and Information Flow Mapping."

The map is a sketch of an entire process that typically ranges from incoming goods from suppliers to shipment of a product or delivery of a service to the customer. The map shows all processes in the value stream, from arrivals of supplies to the shipping of the product. The objective is to increase value to the customer, where value is typically defined in terms of quality, time, cost, or flexibility (e.g., rapid response or agility). Data collected during the mapping process might include times (e.g., cycle time, setup time, changeover time, touch time, lead time), distances traveled (e.g., by parts, workers, paperwork), mistakes (e.g., product defects, data entry errors), inefficient work methods (e.g., extra motions, excessive lifting or moving, repositioning), and waiting lines (e.g., workers waiting for parts or equipment repairs, orders waiting to be processed). Information flows are also included in the mapping process.

You can get a sense of value stream mapping from the following tips for developing an effective mapping of a value stream:[3]

1. Map the value stream in person.
2. Begin with a quick walk through of the system from beginning to end to get a sense of the system.
3. Then do a more thorough walkthrough following the actual pathway to collect current information on material or information flow.
4. Record elements of the system such as cycle times, scrap rates, amounts of inventory, downtimes, number of operators, distances between processes, and transfer times.

Value improvement for a product or a service embodies the five lean principles described earlier and repeated here. It begins by specifying value from the customer's standpoint. You can see where value stream mapping can help process improvement:

1. Specify value from the standpoint of the end customer.
2. Identify all the steps in the value stream and create a visual (map) of the value stream.
3. Eliminate steps that do not create value to create flow.
4. Use next-customer-in-the-process demand to pull from each preceding process as needed to control the flow.
5. Repeat this process as long as waste exists in the system.

Once a value stream map is completed, data analysis can uncover improvement opportunities by asking key questions, such as:

Where are the process bottlenecks?

Where do errors occur?

Which processes have to deal with the most variation?

Where does waste occur?

All business organizations, whether they are primarily engaged in service or manufacturing, can benefit by applying lean principles to their office operations. This includes purchasing, accounting, order entry, and other office functions. Office wastes might include:

1. **Excess inventory**—excess supplies and equipment.
2. **Overprocessing**—excess paperwork and redundant approvals.

[3]Adapted from Rother, Mike, and John Shook. *Learning to See.* Cambridge, MA: Lean Enterprise Institute, 2009.

3. **Waiting times**—orders waiting to be processed, requests for information awaiting answers.
4. **Unnecessary transportation**—inefficient routing.
5. **Processing waste**—using more resources than necessary to accomplish a task.
6. **Inefficient work methods**—poor layout design, unnecessary steps, inadequate training.
7. **Mistakes**—order entry errors, lost files, miscommunications.
8. **Underused people**—Not tapping all of the mental and creative capabilities of workers.

Process Improvement Using 5W2H

5W2H approach A method of asking questions about a process that includes what, why, where, when, who, how, and how much.

Asking certain questions about a process can lead to cost and waste reduction. The **5W2H approach** (five questions that begin with *w,* and two questions that begin with *h*) is outlined in Table 14.4. This approach can be used by itself or in conjunction with value stream mapping.

Lean and Six Sigma

Some believe that lean and six sigma are two alternate approaches for process improvement. However, another view is that the two approaches are complementary and, when used together, can lead to superior results.

Lean strives to eliminate non-value-added activities, using simple tools to find and eliminate them. It focuses on maximizing process velocity, and it employs tools to analyze and improve process flow. However, variation exists in all processes. Understanding and reducing variation are important for quality improvement. Lean principles alone cannot achieve statistical process control, and six sigma alone cannot achieve improved process speed and flow. Using the two approaches in combination integrates lean principles and six sigma statistical tools for variation reduction to achieve a system that has both a balanced flow and quality.

JIT Deliveries and the Supply Chain

Direct suppliers must be able to support frequent just-in-time deliveries of small batches of parts. That may lead to an increase in transportation costs if trucks carry partial loads, and perhaps to congestion at loading docks. Moreover, the JIT delivery requirement may extend to other portions of the supply chain, in which case close coordination among supply chain partners is critical. Also, JIT delivery results in pressure for on-time deliveries to avoid production interruptions due to stockouts.

TABLE 14.4
The 5W2H approach

Category	5W2H	Typical Questions	Goal
Subject	What?	What is being done?	Identify the focus of analysis.
Purpose	Why?	Why is this necessary?	Eliminate unnecessary tasks.
Location	Where?	Where is it being done? Why is it done there? Would it be better to do it someplace else?	Improve the location.
Sequence	When?	When is it done? Would it be better to do it at another time?	Improve the sequence.
People	Who?	Who is doing it? Could someone else do it better?	Improve the sequence or output.
Method	How?	How is it being done? Is there a better way?	Simplify tasks, improve output.
Cost	How much?	How much does it cost now? What would the new cost be?	Select an improved method.

Source: Adapted from Alan Robinson, ed., *Continuous Improvement in Operations: A Systematic Approach to Waste Reduction,* p. 246. Copyright © 1991 Productivity Press. www.productivitypress.com.

Nearby Suppliers Match Ford's Mix

READING

Ford Motor Company took a page out of Toyota's just-in-time book at its Chicago plant by having some of its suppliers locate very close to its assembly plant. It leased production facilities on its 155 acres to about 10 key suppliers. Suppliers' parts and components feed directly into Ford's assembly operation, carefully coordinated to match the sequence of vehicles Ford is producing, which can range from small cars to SUVs. Not only are suppliers nearby in case problems arise, the shortened travel distance and lead times yield tremendous savings in the pipeline inventories of parts and materials.

Lean and ERP

Lean systems focus on pacing production and synchronizing delivery of incoming supply. SAP's Lean Planning and Operations module extends ERP to lean operation by providing lean planning and scheduling capability linked to customer demand. It enables leveling of schedules and synchronization of supply chain activities with paced company operations.

14.5 TRANSITIONING TO A LEAN SYSTEM

The success of lean systems in Japan and the United States has attracted keen interest among other traditional manufacturers.

Planning a Successful Conversion

LO14.10 Outline considerations for successful conversion from a traditional system to a lean system.

To increase the probability of successful transition, companies should adopt a carefully planned approach that includes the following elements:

1. Make sure top management is committed to the conversion and that they know what will be required. Make sure that management is involved in the process and knows what it will cost, how long it will take to complete the conversion, and what results can be expected.
2. Study the operations carefully; decide which parts will need the most effort to convert.
3. Obtain the support and cooperation of workers. Prepare training programs that include sessions in setups, maintenance of equipment, cross-training for multiple tasks, cooperation, and problem solving. Make sure workers are fully informed about what lean is and why it is desirable. Reassure workers that their jobs are secure.
4. Begin by trying to reduce setup times while maintaining the current system. Enlist the aid of workers in identifying and eliminating existing problems (e.g., bottlenecks, poor quality).
5. Gradually convert operations, beginning at the *end* of the process and working *backward.* At each stage, make sure the conversion has been relatively successful before moving on. Do not begin to reduce inventories until major problems have been resolved.
6. As one of the last steps, convert suppliers to JIT and be prepared to work closely with them. Start by narrowing the list of vendors, identifying those who are willing to embrace the lean philosophy. Give preference to vendors who have long-term track records of reliability. Use vendors located nearby if quick response time is important. Establish long-term commitments with vendors. Insist on high standards of quality and adherence to strict delivery schedules.
7. Be prepared to encounter obstacles to conversion.

Obstacles to Conversion

LO14.11 Describe some of the obstacles to lean success.

Converting from a traditional system to a lean system may not be smooth. For example, *cultures* vary from organization to organization. Some cultures relate better to the lean philosophy than others. If a culture doesn't relate, it can be difficult for an organization to change its culture within a short time. Also, manufacturers that operate with large amounts of inventory to handle varying customer demand may have difficulty acclimating themselves to less inventory.

Some other obstacles include the following:

1. Management may not be totally committed or may be unwilling to devote the necessary resources to conversion. This is perhaps the most serious impediment because the conversion is probably doomed without serious commitment.
2. Workers and/or management may not display a cooperative spirit. The system is predicated on cooperation. Managers may resist because lean shifts some of the responsibility from management to workers and gives workers more control over the work. Workers may resist because of the increased responsibility and stress.
3. It can be very difficult to change the culture of the organization to one consistent with the lean philosophy.
4. Suppliers may resist for several reasons:
   a. Buyers may not be willing to commit the resources necessary to help them adapt to the lean systems.
   b. They may be uneasy about long-term commitments to a buyer.
   c. Frequent, small deliveries may be difficult, especially if the supplier has other buyers who use traditional systems.
   d. The burden of quality control will shift to the supplier.
   e. Frequent engineering changes may result from continuing lean improvements by the buyer.

A Cooperative Spirit

Lean systems require a cooperative spirit among workers, management, and vendors. Unless that is present, it is doubtful that a truly effective lean system can be achieved. The Japanese have been very successful in this regard, partly because respect and cooperation are ingrained in the Japanese culture. In Western cultures, workers, managers, and vendors have historically been strongly at odds with each other. Consequently, a major consideration in converting to a lean system is whether a spirit of mutual respect and cooperation can be achieved. This requires an appreciation of the importance of cooperation and a tenacious effort by management to instill and maintain that spirit.

Finally, it should be noted that not all organizations lend themselves to a lean approach. Lean is best used for repetitive operations under fairly stable demand.

Despite the many advantages of lean production systems, an organization must take into account a number of other considerations when planning a conversion.

The key considerations are the time and cost requirements for successful conversion, which can be substantial. But it is absolutely essential to eliminate the major sources of disruption in the system. Management must be prepared to commit the resources necessary to achieve a high level of quality and to function on a tight schedule. That means attention to even the smallest of details during the design phase and substantial efforts to debug the system to the point where it runs smoothly. Beyond that, management must be capable of responding quickly when problems arise, and both management and workers must be committed to the continuous improvement of the system. Although each case is different, a general estimate of the time required for conversion is one to three years.

14.6 LEAN SERVICES

The discussion of lean systems has focused on manufacturing simply because that is where it was developed, and where it has been used most often. It is important to recognize that the full spectrum of lean benefits are more difficult to achieve in service operations. Nonetheless, services can and do benefit from many lean concepts. When just-in-time is used in the context of services, the focus is often on the time needed to perform a service—because speed is often an important order winner for services. Some services do have inventories of some sort, so

The Pyxis® ProcedureStation™ system provides rapid access to inventory in the operating room, cath and cardiac labs, and other specialty departments. Usage, inventory, and replenishment information are transmitted electronically, creating an efficient supply management and workflow process.

inventory reduction is another aspect of lean that can apply to services. Examples of speedy delivery ("available when requested") are Domino's Pizza, FedEx and Express Mail, fast-food restaurants, and emergency services. Other examples include just-in-time publishing and work cells at fast-food restaurants.

In addition to speed, lean services emphasize consistent, high-quality, standard work methods; flexible workers; and close supplier relationships.

Process improvement and problem solving can contribute to streamlining a system, resulting in increased customer satisfaction and higher productivity. The following are the ways lean benefits can be achieved in services:

- **Eliminate disruptions.** For example, try to avoid having workers who are servicing customers also answer telephones.
- **Make the system flexible.** This can cause problems unless approached carefully. Often, it is desirable to standardize work because that can yield high productivity. On the other hand, being able to deal with variety in task requirements can be a competitive advantage. One approach might be to train workers so that they can handle more variety. Another might be to assign work according to specialties, with certain workers handling different types of work according to their specialty.
- **Reduce setup times and processing times.** Have frequently used tools and spare parts readily available. Additionally, for service calls, try to estimate what parts and supplies might be needed so they will be on hand, and avoid carrying huge inventories.
- **Eliminate waste.** This includes errors and duplicate work. Keep the emphasis on quality and uniform service.
- **Minimize work-in-process.** Examples include orders waiting to be processed, calls waiting to be answered, packages waiting to be delivered, trucks waiting to be unloaded or loaded, applications waiting to be processed.
- **Simplify the process.** This works especially when customers are part of the system (self-service systems including retail operations, ATMs and vending machines, service stations, etc.).

To Build a Better Hospital, Virginia Mason Takes Lessons from Toyota Plants

READING

When you think of a hospital, what comes to mind? Patients, emergency rooms, technology and medical advancements. Making the sick and injured well again.

When officials at Virginia Mason think of hospitals, they think of cars. A car manufacturing plant, to be exact.

Beginning in 2000 the hospital's leaders looked at their infrastructure and saw it was designed around them, not the patient, said Dr. Gary Kaplan, Virginia Mason's chairman and chief executive officer.

For example, you hurry up and be on time, only to wait for the physician to see you.

They began looking for a better way to improve quality, safety and patient satisfaction. After two years of searching, they discovered the Toyota Production System, also known as lean manufacturing. Developed in part by Japanese businessman Taiichi Ohno, the idea is to eliminate waste and defects in production. Virginia Mason has tailored the Japanese model to fit health care.

Kaplan and other Virginia Mason managers took their first trip to Japan in 2002 where they visited manufacturing plants such as Toyota and Yamaha. Nearly 200 employees have toured plants in Japan and a ninth trip is planned for this summer. While Virginia Mason couldn't say exactly how much they paid over the years to send the staff overseas, officials liken it to leadership training other companies pay for their employees. They say the benefits offset the costs.

"'People are not cars' is very common for me to hear," Kaplan said. "We get so wrapped up in the seriousness and specialness of health care, but we also have to open our eyes to other industries—we're way behind in information specialists and taking waste out of our process. Toyota is obsessed with the customer and customer satisfaction . . . all those things Toyota was about was what we wanted."

So what does that mean?

There are seven wastes, according to the production system. One is wasting time, such as patients waiting for a doctor or for test results to come back. Others are inventory waste—having more materials and information than is necessary—and overproduction waste, producing more than is necessary.

Take, for example, stockpiling brochures and pamphlets in storage closets. They take up space. There is wasted cost to make so many pamphlets that aren't needed.

The hospital and all of its campuses in the Seattle area implemented a Kanban system, which signals the need to restock. Kanban, which means "visual card" in Japanese, uses exactly that—a card put near the bottom of a pile of tongue dispensers, gauze strips or brochures, for example. When a nurse or physician sees the card, he or she knows it's time to refill. Supplies don't run out, but they also aren't over-ordered.

The hospital created standardized instrument trays for surgeries and procedures, which saved several hundred dollars by no longer setting out extra instruments no one used. Unused but opened instruments have to be thrown away.

It takes a series of simple steps to make improvements, said Janine Wentworth, an administrative director who returned from a two-week trip to Japan last month. One example is the development of a flip chart showing the level of mobility in physical therapy patients. The chart shows the appropriate picture of what the patient can do, and each nurse or physician who comes in the room doesn't have to waste time searching charts or asking questions.

Wentworth also wants to implement a production plan to hire more staff before a shortage exists based on turnover rates on any given hospital floor.

Another adaptation from the Toyota model is a patient safety alert system. At the manufacturing plant, if there's a problem, the whole line is stopped and the problem is fixed immediately. Virginia Mason's practice had been to identify and fix problems after the fact, perhaps leading to mistakes recurring many times before a solution was found. The alert system allows nurses and physicians to signal a problem when it happens and fix it immediately. Virginia Mason's Kirkland site has about 10 alerts each day.

The Kirkland campus implemented the Toyota model in 2003. They've reduced appointment and telephone delays by having medical assistants handle incoming calls, instead of medically untrained operators.

Also, instead of doctors waiting until the end of the day to go through a stack of patient records, they now write comments and recommendations immediately after seeing the patient before going to see the next one. The time saved increases the time a physician can spend with a patient. Dr. Kim Pittenger, medical director at Virginia Mason Kirkland, said most of the cost of medical care involves clogs in the flow of information—paper forms, lab results, phone messages, often leading to irritated patients. Working the backlog down costs more than if you never let things pile up in the first place, he said.

He said not everyone has agreed with the new system and a few physicians have left Virginia Mason because of it.

"To some it seems like obsessive-compulsive disorder run amok, but it's part of a solution that eliminates mistakes," Pittenger said.

Other hospitals, including Swedish Medical Center, have incorporated the lean system into parts of their operation.

Virginia Mason said overall benefits include an 85 percent reduction in how long patients wait to get lab results back, and lowering inventory costs by $1 million. They've redesigned facilities to make patient and staff work flow more productive. The hospital reduced overtime and temporary labor expenses by $500,000 in one year and increased productivity by 93 percent. While direct cost savings aren't passed on to patients with the new system, less waiting, increased safety and more efficient care are.

Kaplan's vision is to have patients start their appointment in the parking garage with a smart card that triggers their entire appointment process. No more waiting rooms, just move directly from the garage to an examination room.

Total flow—no waiting, no waste and it's all about the patient.

"We have more than enough resources in health care," Kaplan said. "We just need to stop wasting it and only do what's appropriate and value-added and we'd save billions."

Source: Cherie Black, "To Build a Better Hospital, Virginia Mason Takes Lessons from Toyota Plant," *Seattle Post-Intelligencer,* March 15, 2008.

JIT service can be a major competitive advantage for companies that can achieve it. An important key to JIT service is the ability to provide service when it is needed. That requires flexibility on the part of the provider, which generally means short setup times, and it requires clear communication on the part of the requester. If a requester can determine when it will need a particular service, a JIT server can schedule deliveries to correspond to those needs, eliminating the need for continual requests, and reducing the need for provider flexibility—and therefore probably reducing the cost of the JIT service.

Although lean concepts are applicable to service organizations, the challenge of implementing lean in service is that there are still relatively few lean service applications that service companies can reference to see how to apply the underlying lean principles. Consequently, it can be difficult to build a strong commitment among workers to achieve a lean service system.

14.7 JIT II

In some instances, companies allow *suppliers* to manage restocking of inventory obtained from the suppliers. A supplier representative works right in the company's plant, making sure there is an appropriate supply on hand. The term *JIT II* is used to refer to this practice. JIT II was popularized by the Bose Corporation. It is often referred to as *vendor-managed inventory (VMI)*. You can also read more about vendor-managed inventories in the supply chain management chapter (Chapter 15).

14.8 OPERATIONS STRATEGY

The lean operation offers new perspectives on operations that must be given serious consideration by managers in repetitive and batch systems who wish to be competitive.

Potential adopters should carefully study the requirements and benefits of lean production systems, as well as the difficulties and strengths of their current systems, before making a decision on whether to convert. Careful estimates of time and cost to convert, and an assessment of how likely workers, managers, and suppliers are to cooperate in such an approach, are essential.

The decision to convert can be sequential, giving management an opportunity to gain first-hand experience with portions of lean operations without wholly committing themselves. For instance, improving vendor relations, reducing setup times, improving quality, and reducing waste and inefficiency are desirable goals in themselves. Moreover, a level production schedule is a necessary element of a lean system, and achieving that will also be useful under a traditional system of operation.

It is prudent to carefully weigh the risks and benefits of a just-in-time approach to inventories. A just-in-time approach can make companies and even countries vulnerable to disruptions in their supply chains. For example, low stockpiles of flu vaccine at hospitals lower their costs but leave the health system at risk if there is a flu outbreak. Also, severe weather such as hurricanes, floods, and tornadoes, and other natural disasters caused by earthquakes can cut off supply routes, leaving community services as well as companies desperately in need of supplies.

Supplier management is critical to a JIT operation. Generally, suppliers are located nearby to facilitate delivery on a daily or even hourly basis. Moreover, suppliers at every stage must gauge the ability of their production facilities to meet demand requirements that are subject to change.

Finally, the success of a lean system relies heavily on leadership commitment, involvement, and support, achieving a lean thinking "culture" that includes everyone in the organization, and having effective teamwork. Without these three elements, the full benefits of lean are not likely to be realized.

SUMMARY

Lean operation is an alternative to traditional operation that an increasing number of organizations are adopting. The ultimate goal of a lean system is to achieve a balanced, smooth flow of operations. Supporting goals include eliminating disruptions to the system, making the system flexible, and eliminating waste. The building blocks of a lean production system are product design, process design, personnel and organization, and manufacturing planning and control.

Lean systems require the elimination of sources of potential disruption to the even flow of work. High quality is essential because problems with quality can disrupt the process. Quick, low-cost setups, special layouts, allowing work to be pulled through the system rather than pushed through, and a spirit of cooperation are important features of lean systems. So, too, are problem solving aimed at reducing disruptions and making the system more efficient, and an attitude of working toward continual improvement.

Key benefits of lean systems are reduced inventory levels, high quality, flexibility, reduced lead times, increased productivity and equipment utilization, reduced amounts of scrap and rework, and reduced space requirements. The risks stem from the absence of buffers, such as extra personnel and inventory stockpiles to fall back on if something goes wrong. The possible results of risks include lost sales and lost customers.

Just-in-time (JIT) is a system of lean production used mainly in repetitive operations, in which goods move through the system and tasks are completed just in time to maintain the schedule. JIT systems require very little inventory because successive operations are closely coordinated. Careful planning and much effort are needed to achieve a smoothly functioning system in which all resources needed for production come together at precisely the right time throughout the process. Raw materials and purchased parts must arrive when needed, fabricated parts and subassemblies must be ready when needed for final assembly, and finished goods must be delivered to customers when needed. Special attention must be given to reducing the risk of disruptions to the system as well as rapid response to resolving any disruptions that do occur. Usually, a firm must redesign its facilities and rework labor contracts to implement lean operation. Teamwork and cooperation are important at all levels, as are problem-solving abilities of workers and an attitude of continuous improvement.

Table 14.5 provides an overview of lean.

TABLE 14.5
Overview of lean

Lean systems are designed to operate with fewer resources than traditional systems.

Elements of lean operation include:

- Smooth flow of work (the ultimate goal).
- Elimination of waste.
- Continuous improvement.
- Elimination of anything that does not add value.
- Simple systems that are easy to manage.
- Use of product layouts that minimize time spent moving materials and parts.
- Quality at the source: Each worker is responsible for the quality of his or her output.
- *Poka-yoke:* fail-safe tools and methods to prevent mistakes.
- Preventive maintenance to reduce the risk of equipment breakdown.
- Good housekeeping: an orderly and clean workplace.
- Setup time reduction.
- Cross-trained workers.
- A pull system.

There are seven types of waste:

- Inventory.
- Overproduction.
- Waiting time.
- Excess transportation.
- Processing waste.
- Inefficient work methods.
- Product or service defects.

KEY POINTS

1. Lean systems produce high-quality goods or services using fewer resources than traditional operations systems.
2. Lean thinking helps business organizations to become more productive, reduce costs, and be more market-responsive.
3. Lean operations are designed to eliminate waste (value stream mapping), minimize inventory (JIT deliveries), maximize work flow (small batches with quick changeovers), make only what is needed (demand pull), empower work teams, do it right the first time (quality at the source), and continually improve.

KEY TERMS

SOLVED PROBLEMS

Problem 1

Determine the number of containers needed for a workstation that uses 100 parts per hour if the time for a container to complete a cycle (move, wait, empty, return, fill) is 90 minutes and a standard container holds 84 parts. An inefficiency factor of .10 is currently being used.

Solution

$N = ?$

$D = 100$ parts per hour

$T = 90$ minutes (1.5 hours)

$C = 84$ parts

$X = .10$

$$N = \frac{D(T)(1 + X)}{C} = \frac{100(1.5)(1 + .10)}{84} = 1.96; \text{ round to 2 containers}$$

Problem 2

Determine the number of cycles per day and the production quantity per cycle for this set of products. The department operates five days a week. Assume the sequence A-B-C-D will be used.

Product	Weekly Quantity
A	20
B	40
C	30
D	15

Solution

Convert weekly quantities to daily quantities. The smallest *daily* quantity is 3 units. Producing in multiples of 3 units leaves A and B a few units short:

Product	Daily Quantity = Weekly Quantity ÷ 5	Units Short Using 3 Cycles
A	20 ÷ 5 = 4	1
B	40 ÷ 5 = 8	2
C	30 ÷ 5 = 6	—
D	15 ÷ 5 = 3	—

Use three cycles, producing all four products in every cycle. Produce units that are short by adding units to some cycles. Disperse the additional units as evenly as possible. There are several possibilities. One is

Cycle	1	2	3
Pattern	A B(3) C(2) D	A B(3) C(2) D	A(2) B(2) C(2) D
Extra unit(s)	B	B	A

DISCUSSION AND REVIEW QUESTIONS

1. Some key elements of production systems are listed in Table = 14.3. Explain briefly how lean systems differ from traditional production systems for each of those elements.
2. What is the ultimate goal of a lean system? What are the supporting goals? What are the building blocks?
3. Describe the philosophy that underlies JIT (i.e., what is JIT intended to accomplish?).
4. What are some of the main obstacles that must be overcome in converting from a traditional system to lean?
5. Briefly discuss vendor relations in lean systems in terms of the following issues:
   a. Why are they important?
   b. How do they tend to differ from the more adversarial relations of the past?
   c. Why might suppliers be hesitant about JIT purchasing?
6. Certain Japanese have claimed that Henry Ford's assembly line provided some of the rationale for lean. What features of assembly lines are common to lean systems?
7. What is the kanban aspect of JIT?
8. Contrast push and pull methods of moving goods and materials through production systems.
9. What are the main benefits of a lean system?
10. What are the benefits and risks of small lot sizes?

TAKING STOCK

1. What trade-offs are involved in shifting from a traditional operations system to a lean system for:
   a. A manufacturing firm?
   b. A service firm?
2. Who in the organization is affected by a decision to shift from a traditional operations system to a lean system?
3. To what extent has technology had an impact on lean systems?

CRITICAL THINKING EXERCISES

1. In operations management, as in life, a balanced approach is often the best policy. One of the best examples of the benefits of this in operations management is the lean approach. Explain the basic factors that must be in place in order to achieve a balanced lean system.
2. Give three examples of unethical behavior involving lean operations, and state the relevant ethical principle that would be violated.

PROBLEMS

1. A manager wants to determine the number of containers to use for incoming parts for a kanban system to be installed next month. The process will have a usage rate of 80 pieces per hour. Because the process is new, the manager has assigned an inefficiency factor of .35. Each container holds 45 pieces, and it takes an average of 75 minutes to complete a cycle. How many containers should be used? As the system improves, will more or fewer containers be required? Why?
2. A JIT system uses kanban cards to authorize movement of incoming parts. In one portion of the system, a work center uses an average of 100 parts per hour while running. The manager has assigned an inefficiency factor of .20 to the center. Standard containers are designed to hold six dozen parts each. The cycle time for parts containers is about 105 minutes. How many containers are needed?
3. A machine cell uses 200 pounds of a certain material each day. Material is transported in vats that hold 20 pounds each. Cycle time for the vats is about two hours. The manager has assigned an inefficiency factor of .08 to the cell. The plant operates on an eight-hour day. How many vats will be used?
4. Determine the number of cycles per day and the production quantity per cycle for this set of vehicles:

Product	Daily Quantity
A	21
B	12
C	3
D	15

Use the sequence A-B-C-D.

5. Given this set of daily service operations, and assuming a processing order of A-B-C-D-E:
   a. Give one reason that each arrangement might be preferred over the other.
   b. Determine the number of repetitions for each service if four cycles are used.
   c. Determine the number of repetitions for each service if two cycles are used.

Service Operation	Number of Daily Reps
A	22
B	12
C	4
D	18
E	8

6. Determine the number of cycles per day and a production quantity per cycle for this set of products that achieves fairly level production:

Product	Daily Quantity
F	9
G	8
H	5
K	6

Assume the production sequence will be F-G-H-K.

7. Compute the *takt* time for a system where the total time per shift is 480 minutes, there is one shift, and workers are given two 15-minute breaks and 45 minutes for lunch. Daily demand is 300 units.
8. What cycle time would match capacity and demand if demand is 120 units a day, there are two shifts of 480 minutes each, and workers are given three half-hour breaks during each shift, one of which is for lunch or dinner?
9. Compute the *takt* time for a service system that intended to perform a standardized service. The system will have a total work time of 440 minutes per day, two 10-minute breaks, and an hour for lunch. The service system must process 90 jobs a day.

Level Operations

CASE

Level Operations is a small company located in eastern Pennsylvania. It produces a variety of security devices and safes. The safes come in several different designs. Recently, a number of new customers have placed orders, and the production facility has been enlarged to accommodate increased demand for safes. Production manager Stephanie Coles is currently working on a production plan for the safes. She needs a plan for each day of the week. She has obtained the following information from the marketing department on projected demand for the next five weeks:

Model	S1	S2	S7	S8	S9
Weekly Quantity	120	102	48	90	25

The department operates five days a week. One complexity is that partially completed safes are not permitted; each cycle must turn out finished units.

After discussions with engineering, Stephanie determined that the best production sequence for each cycle is S7-S8-S9-S1-S2.

Question

What might Stephanie determine as the best production quantity per cycle for each day of the week?

Boeing

OPERATIONS TOUR

The Boeing Company, headquartered in Chicago, Illinois, is one of the two major producers of aircraft in the global market. The other major producer is European Airbus.

Boeing produces three models in Everett, Washington: 747s, 767s, and 777s. The planes are all produced in the same building. At any one time, there may be as many as six planes in various stages of production. Obviously the building has to be fairly large to accommodate such a huge undertaking. In fact, the building is so large that it covers over 98 acres and it is four stories high, making it the largest building by volume in the world. It is so large that all of Disneyland would fit inside, and still leave about 15 acres for indoor parking! The windowless building has six huge doors along one side, each about 100 yards wide and 40 yards high (the size of a football field)—large enough to allow a completed airplane to pass through.

Boeing sells airplanes to airlines and countries around the globe. There isn't a set price for the planes; the actual price depends on what features the customer wants. Once the details have been settled and an order submitted, the customer requirements are sent to the design department.

Design

Designers formerly had to construct a mock-up to determine the exact dimensions of the plane and to identify any assembly problems that might occur. That required time, materials, labor, and space. Now they use computers (CAD) to design airplanes, avoiding the cost of the mock-ups and shortening the development time.

The Production Process

Once designs have been completed and approved by the customer, production of the plane is scheduled, and parts and materials are ordered. Parts come to the plant by rail, airplane, and truck, and are delivered to the major assembly area of the plane they will be used for. The parts are scheduled so they arrive at the plant just prior to when they will be used in assembly, and immediately moved to storage areas close to where they will be used. Time-phasing shipments to arrive as parts are needed helps to keep inventory investment low and avoids having to devote space to store parts that won't be used immediately. There is a trade-off, though, because if any parts are missing or damaged and have to be reordered, that could cause production delays. When missing or defective parts are discovered, they are assigned priorities according to how critical the part is in terms of disruption of the flow of work. The parts with the highest priorities are assigned to expediters who determine the best way to replace the part. The expediters keep track of the progress of the parts and deliver them to the appropriate location as soon as they arrive. In the meantime, a portion of the work remains unfinished, awaiting the replacement parts, and workers complete other portions of the assembly. If the supplier is unable to replace the part in a time frame that will not seriously delay assembly, as a last resort, Boeing has a machine shop that can make the necessary part.

The partially assembled portions of the plane, and in later stages, the plane itself, move from station to station as the work progresses, staying about five days at each station. Giant overhead cranes are used to move large sections from one station to the next, although once the wheel assemblies have been installed, the plane is towed to the remaining stations.

Finished planes are painted in one of two separate buildings. Painting usually adds 400 to 600 pounds to the weight of a plane. The painting process involves giving the airplane a negative charge and the paint a positive charge so that the paint will be attracted to the airplane.

Testing and Quality Control

Boeing has extensive quality control measures in place throughout the entire design and production process. Not only are there quality inspectors, individual employees inspect their own work and the work previously done by others on the plane. Buyers' inspectors also check on the quality of the work.

There are 60 test pilots who fly the planes. Formerly planes were tested to evaluate their flight worthiness in a wind tunnel, which required expensive testing and added considerably to product development time. Now new designs are tested using a computerized wind tunnel before production even begins, greatly reducing both time and cost. And in case you're wondering, the wings are fairly flexible; a typical wing can flap by as much as 22 feet before it will fracture.

Re-engineering

Boeing is re-engineering its business systems. A top priority is to upgrade its computer systems. This will provide better links to suppliers, provide more up-to-date information for materials management, and enable company representatives who are at customer sites to create a customized aircraft design on their laptop computer.

Another aspect of the re-engineering involves a shift to lean production. Key goals are to reduce production time and reduce inventory.

Boeing wants to reduce the time that a plane spends at each work station from 5 days to 3 days, a reduction of 40 percent. Not only will that mean that customers can get their planes much sooner, it will also reduce labor costs and inventory costs, and improve cash flow. One part of this will be accomplished by moving toward late-stage customization, or delayed differentiation. That would mean standardizing the assembly of planes as long as possible before adding custom features. This, and other time-saving steps, will speed up production considerably, giving it a major competitive advantage. It also wants to reduce the tremendous amount of inventory it carries (a 747 jumbo jet has about 6 million parts, including 3 million rivets). One part of the plan is to have suppliers do more predelivery work by assembling the parts into kits that are delivered directly to the staging area where they will be installed on the aircraft instead of delivering separate parts to inventory. That would cut down on inventory carrying costs and save time.

Boeing is also hoping to reduce the number of suppliers it has, and to establish better links and cooperation from suppliers. Currently Boeing has about 3,500 suppliers. Compare that with GM's roughly 2,500 suppliers, and you get an idea of how large this number is.

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