Lean Operations

CHAPTER 16

CHAPTER OUTLINE

GLOBAL COMPANY PROFILE: *Toyota Motor Corporation*

- Lean Operations *638*
- Lean and Just-in-Time *640*
- Lean and the Toyota Production System *649*
- Lean Organizations *650*
- Lean in Services *652*

Alaska Airlines

10 OM STRATEGY DECISIONS

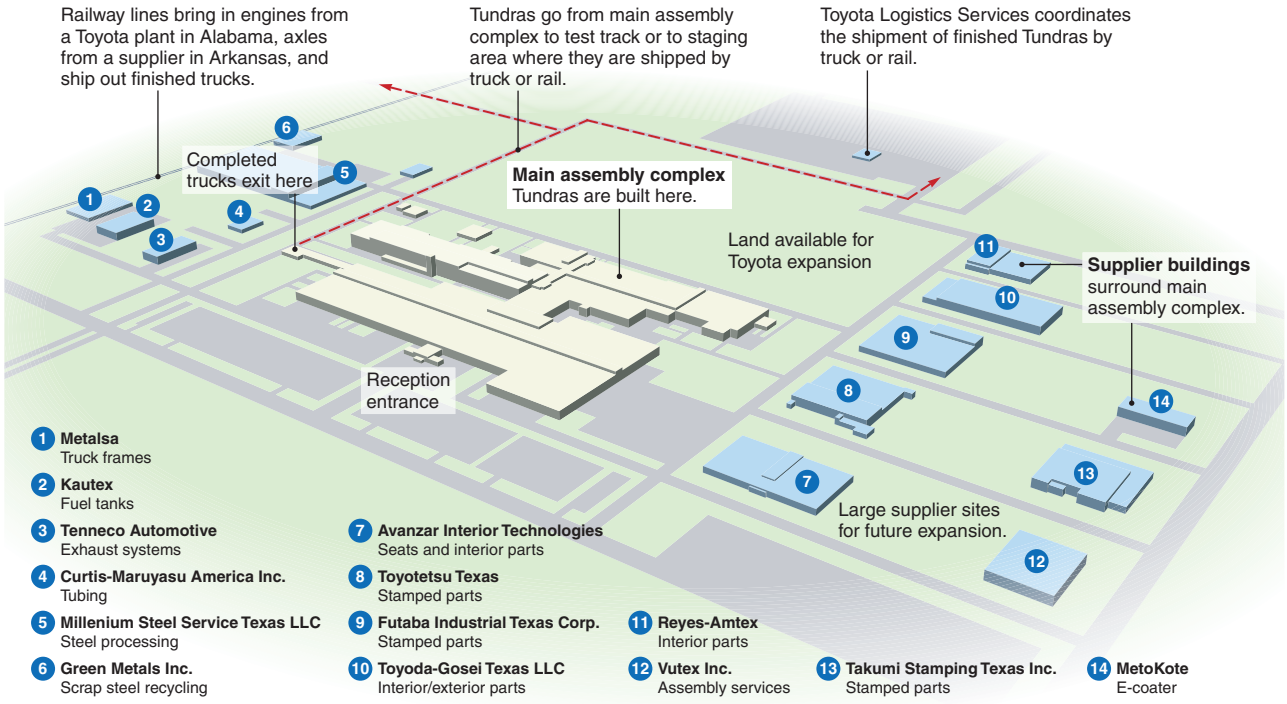
- Design of Goods and Services
- Managing Quality
- Process Strategy
- Location Strategies
- Layout Strategies
- Human Resources
- Supply-Chain Management
- *Inventory Management*
  - Independent Demand (Ch. 12)
  - Dependent Demand (Ch. 14)
  - ***Lean Operations (Ch. 16)***
- Scheduling
- Maintenance

GLOBAL COMPANY PROFILE
Toyota Motor Corporation

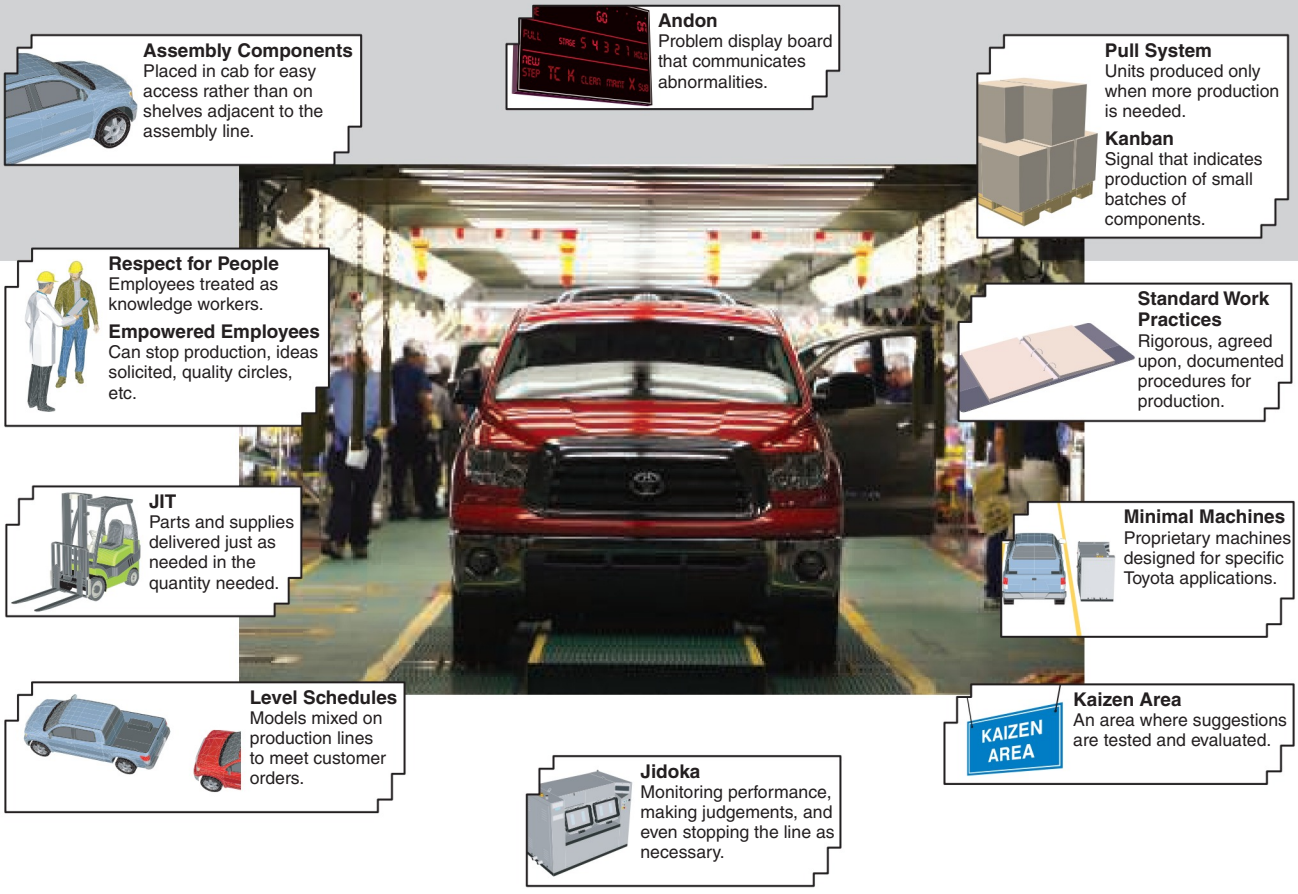
Achieving Competitive Advantage with Lean Operations at Toyota Motor Corporation

Toyota Motor Corporation, with $250 billion in annual sales of over 9 million cars and trucks, is one of the largest vehicle manufacturers in the world. Two Lean techniques, just-in-time (JIT) and the Toyota Production System (TPS), have been instrumental in its growth. Toyota, with a wide range of vehicles, competes head-to-head with successful, long-established companies in Europe and the U.S. Taiichi Ohno, a former vice president of Toyota, created the basic framework for two of the world's most discussed systems for improving productivity, JIT and TPS. These two concepts provide much of the foundation for Lean operations:

- Central to JIT is a philosophy of continuous problem solving. In practice, JIT means making only what is needed, when it is needed. JIT provides an excellent vehicle for finding and eliminating problems because problems are easy to find in a system that eliminates the slack that inventory generates. When excess inventory is eliminated, shortcomings related to quality, layout, scheduling, and supplier performance become immediately evident—as does excess production.
- Central to TPS is employee learning and a continuing effort to create and produce products under ideal conditions. Ideal conditions exist only when management



Outside: Toyota has a 2,000-acre site with 14 of the 21 onsite suppliers, adjacent rail lines, and nearby interstate highway. The site provides expansion space for both Toyota and for its suppliers — and provides an environment for just-in-time.



Seven suppliers inside the main plant

Toyota's San Antonio plant has about 2 million interior sq. ft., providing facilities within the final assembly building for 7 of the 21 onsite suppliers, and capacity to build 200,000 pick-up trucks annually. But most importantly, Toyota practices the world-class Toyota Production System and expects its suppliers to do the same thing, wherever they are.

brings facilities, machines, and people together to add value without waste. Waste undermines productivity by diverting resources to excess inventory, unnecessary processing, and poor quality. Respect for people, extensive training, cross-training, and standard work practices of empowered employees focusing on driving out waste are fundamental to TPS.

Toyota's implementation of TPS and JIT is present at its 2,000-acre San Antonio, Texas, facility, the largest Toyota land site for an automobile assembly plant in the U.S. Interestingly, despite its large site and annual production capability of 200,000, a throughput time of 20½ hours, and the output of a truck every 63 seconds, the building itself is one of the smallest in the industry. Modern automobiles have 30,000 parts, but at Toyota, independent suppliers combine many of these parts into subassemblies. Twenty-one of these suppliers are on site at the San Antonio facility and transfer components to the assembly line on a JIT basis.

Operations such as these taking place in the San Antonio plant are why Toyota continues to perform near the top in quality and maintain the lowest labor-hour assembly time in the industry. Lean operations *do* work—and they provide a competitive advantage for Toyota Motor Corporation.

LEARNING OBJECTIVES

LO 16.1 ***Define*** Lean operations 638
LO 16.2 ***Define*** the seven wastes and the 5Ss 638
LO 16.3 ***Identify*** the concerns of suppliers when moving to supplier partnerships 642
LO 16.4 ***Determine*** optimal setup time 645
LO 16.5 ***Define*** kanban 647
LO 16.6 ***Compute*** the required number of kanbans 648
LO 16.7 ***Identify*** six attributes of Lean organizations 651
LO 16.8 ***Explain*** how Lean applies to services 652

Lean Operations

LO 16.1 *Define* Lean operations

Lean operations
Eliminates waste through continuous improvement and focus on exactly what the customer wants.

Just-in-time (JIT)
Continuous and forced problem solving via a focus on throughput and reduced inventory.

Toyota Production System (TPS)
Focus on continuous improvement, respect for people, and standard work practices.

As shown in the *Global Company Profile*, the Toyota Production System (TPS) contributes to a world-class operation at Toyota Motor Corporation. In this chapter, we discuss Lean operations, including JIT and TPS, as approaches to continuous improvement that lead to world-class operations.

Lean operations supply the customer with exactly what the customer wants when the customer wants it, without waste, through continuous improvement. Lean operations are driven by workflow initiated by the "pull" of the customer's order. **Just-in-time (JIT)** is an approach of continuous and forced problem solving via a focus on throughput and reduced inventory. The **Toyota Production System (TPS)**, with its emphasis on continuous improvement, respect for people, and standard work practices, is particularly suited for assembly lines.

In this chapter we use the term *Lean operations* to encompass all the related approaches and techniques of both JIT and TPS. When implemented as a comprehensive operations strategy, Lean sustains competitive advantage and results in increased overall returns to stakeholders.

Regardless of the approach and label, operations managers address three issues that are fundamental to operations improvement: *eliminate waste, remove variability,* and *improve throughput.* We now introduce these three issues and then discuss the major attributes of Lean operations. Finally, we look at Lean applied to services.

Eliminate Waste

Lean producers set their sights on perfection: *no* bad parts, *no* inventory, *only* value-added activities, and *no* waste. Any activity that does not add value in the eyes of the customer is a waste. The customer defines product value. If the customer does not want to pay for it, it is a waste. Taiichi Ohno, noted for his work on the Toyota Production System, identified seven categories of waste. These categories have become popular in Lean organizations and cover many of the ways organizations waste or lose money. Ohno's **seven wastes** are:

Seven wastes
Overproduction
Queues
Transportation
Inventory
Motion
Overprocessing
Defective product

- *Overproduction:* Producing more than the customer orders or producing early (before it is demanded) is waste.
- *Queues:* Idle time, storage, and waiting are wastes (they add no value).
- *Transportation:* Moving material between plants or between work centers and handling it more than once is waste.
- *Inventory:* Unnecessary raw material, work-in-process (WIP), finished goods, and excess operating supplies add no value and are wastes.
- *Motion:* Movement of equipment or people that adds no value is waste.
- *Overprocessing:* Work performed on the product that adds no value is waste.
- *Defective product:* Returns, warranty claims, rework, and scrap are wastes.

LO 16.2 *Define* the seven wastes and the 5Ss

A broader perspective—one that goes beyond immediate production—suggests that other resources, such as energy, water, and air, are often wasted but should not be. Efficient, sustainable production minimizes inputs and maximizes outputs, wasting nothing.

For over a century, managers have pursued "housekeeping" for a neat, orderly, and efficient workplace and as a means of reducing waste. Operations managers have embellished "housekeeping" to include a checklist—now known as the 5Ss.[1] The Japanese developed the initial 5Ss. Not only are the 5Ss a good checklist for Lean operations, but they also provide an easy vehicle with which to assist the culture change that is often necessary to bring about Lean operations. The **5Ss** follow:

Alaska Airlines

In keeping with 5S, airports, like many other facilities, specify with painted guidelines exactly where tools and equipment such as this fuel pump are to be positioned.

5Ss
A Lean production checklist:
Sort
Simplify
Shine
Standardize
Sustain

- *Sort/segregate:* Keep what is needed and remove everything else from the work area; when in doubt, throw it out. Identify nonvalue items and remove them. Getting rid of these items makes space available and usually improves workflow.
- *Simplify/straighten:* Arrange and use methods analysis tools (see Chapter 7 and Chapter 10) to improve workflow and reduce wasted motion. Consider long-run and short-run ergonomic issues. Label and display for easy use only what is needed in the immediate work area. (For examples of visual displays, see Chapter 10, Figure 10.8 and the adjacent photo of equipment located within prescribed lines on the tarmac at Seattle's airport.)
- *Shine/sweep:* Clean daily; eliminate all forms of dirt, contamination, and clutter from the work area.
- *Standardize:* Remove variations from the process by developing standard operating procedures and checklists; good standards make the abnormal obvious. Standardize equipment and tooling so that cross-training time and cost are reduced. Train and retrain the work team so that when deviations occur, they are readily apparent to all.
- *Sustain/self-discipline:* Review periodically to recognize efforts and to motivate to sustain progress. Use visuals wherever possible to communicate and sustain progress.

U.S. managers often add two additional Ss that contribute to establishing and maintaining a Lean workplace:

- *Safety:* Build good safety practices into the preceding five activities.
- *Support/maintenance:* Reduce variability, unplanned downtime, and costs. Integrate daily *shine* tasks with preventive maintenance.

The Ss support continuous improvement and provide a vehicle with which employees can identify. Operations managers need think only of the examples set by a well-run hospital emergency room or the spit-and-polish of a fire department for a benchmark. Offices and retail stores, as well as manufacturers, have successfully used the 5Ss in their respective efforts to eliminate waste and move to Lean operations. A place for everything and everything in its place does make a difference in a well-run office. And retail stores successfully use the Ss to reduce misplaced merchandise and improve customer service. An orderly workplace reduces waste, releasing assets for other, more productive, purposes.

Remove Variability

Managers seek to remove variability caused by both internal and external factors. **Variability** is any deviation from the optimum process that delivers a perfect product on time, every time. Variability is a polite word for problems. The less variability in a system, the less waste in the system. Most variability is caused by tolerating waste or by poor management. Among the many sources of variability are:

Variability
Any deviation from the optimum process that delivers a perfect product on time, every time.

- Poor processes that allow employees and suppliers to produce improper quantities or nonconforming units
- Inadequate maintenance of facilities and processes
- Unknown and changing customer demands
- Incomplete or inaccurate drawings, specifications, and bills of material

Inventory reduction via JIT is an effective tool for identifying causes of variability. The precise timing of JIT makes variability evident, just as reducing inventory exposes variability. Defeating variability allows managers to move good materials on schedule, add value at each step of the process, drive down costs, and ultimately win orders.

Improve Throughput

Throughput
The rate at which units move through a process.

Manufacturing cycle time
The time between the arrival of raw materials and the shipping of finished products.

Pull system
A concept that results in material being produced only when requested and moved to where it is needed just as it is needed.

Throughput is the rate at which units move through a process. Each minute that products remain on the books, costs accumulate, and competitive advantage is lost. Time is money. The time that an order is in the shop is called **manufacturing cycle time**. This is the time between the arrival of raw materials and the shipping of finished product. For example, phone-system manufacturer Nortel had materials pulled directly from qualified suppliers to the assembly line. This effort reduced a segment of the manufacturing cycle time from 3 weeks to just 4 hours, the incoming inspection staff from 47 to 24, and problems on the shop floor caused by defective materials by 97%. Driving down manufacturing cycle time can make a major improvement in throughput.

A technique for increasing throughput is a pull system. A **pull system** *pulls* a unit to where it is needed just as it is needed. Pull systems are a standard tool of Lean. Pull systems use signals to request production and delivery from supplying stations to stations that have production capacity available. The pull concept is used both within the immediate production process and with suppliers. By *pulling* material through the system in very small lots—just as it is needed—waste and inventory are removed. As inventory is removed, clutter is reduced, problems become evident, and continuous improvement is emphasized. Removing the cushion of inventory also reduces both investment in inventory and manufacturing cycle time. A *push* system dumps orders on the next downstream workstation, regardless of timeliness and resource availability. Push systems are the antithesis of Lean. Pulling material through a production process as it is needed rather than in a "push" mode typically lowers cost and improves schedule performance, enhancing customer satisfaction.

Lean and Just-in-Time

STUDENT TIP
JIT places added demands on performance, but that is why it pays off.

Just-in-time (JIT), with its focus on rapid throughput and reduced inventory, is a powerful component of Lean. With the inclusion of JIT in Lean, materials arrive *where* they are needed only *when* they are needed. When good units do not arrive just as needed, a "problem" has been identified. This is the reason this aspect of Lean is so powerful—it focuses attention on *problems*. By driving out waste and delay, JIT reduces inventory, cuts variability and waste, and improves throughput. Every moment material is held, an activity that adds value should be occurring. Consequently, as Figure 16.1 suggests, JIT often yields a competitive advantage.

A well-executed Lean program requires a meaningful buyer–supplier partnership.

Culinary Institute of America

Many services have adopted Lean techniques as a normal part of their business. Restaurants like Olive Garden expect and receive JIT deliveries. Both buyer and supplier expect fresh, high-quality produce delivered without fail just when it is needed. The system doesn't work any other way.

Supplier Partnerships

Supplier partnerships
Partnerships of suppliers and purchasers that remove waste and drive down costs for mutual benefits.

Supplier partnerships exist when a supplier and a purchaser work together with open communication and a goal of removing waste and driving down costs. Trust and close collaboration are critical to

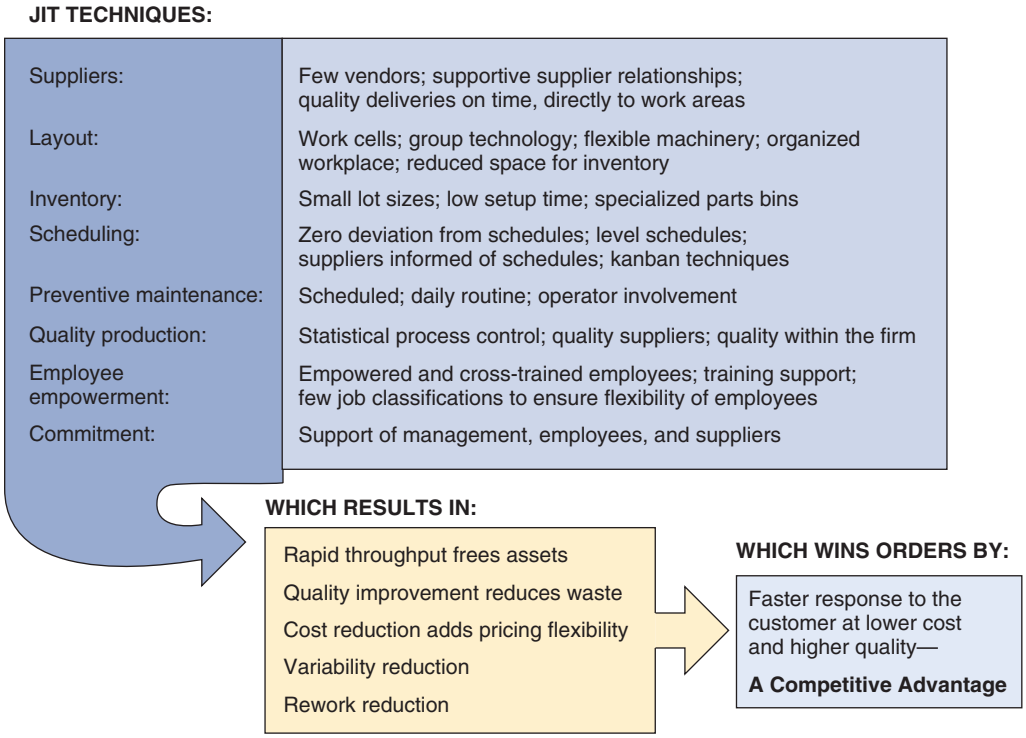


Figure 16.1
Lean Contributes to Competitive Advantage

the success of Lean. Figure 16.2 shows the characteristics of supplier partnerships. Some specific goals are:

- *Removal of unnecessary activities*, such as receiving, incoming inspection, and paperwork related to bidding, invoicing, and payment.
- *Removal of in-plant inventory* by delivery in small lots directly to the using department as needed.

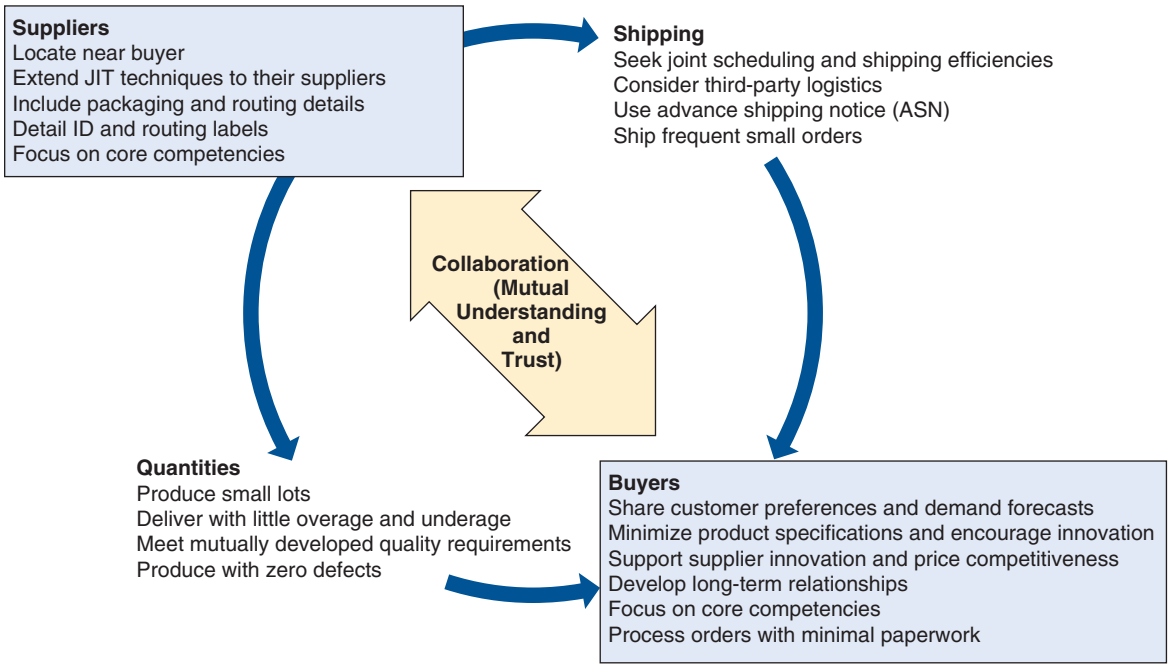


Figure 16.2
Characteristics of Supplier Partnerships

OM in Action Lean Production at Cessna Aircraft Company

When Cessna Aircraft opened its new plant in Independence, Kansas, it saw the opportunity to switch from craftwork to a Lean manufacturing system. The initial idea was to focus on three Lean concepts: (1) vendor-managed inventory, (2) cross-training of employees, and (3) using technology and manufacturing cells to move away from batch processing.

After several years, with these goals accomplished, Cessna began working on the next phase of Lean. This phase focuses on *Team Build* and *Area Team Development.*

Team Build at Cessna empowers employees to expand their skills, sequence their own work, and then sign off on it. This reduces wait time, inventory, part shortages, rework, and scrap, all contributing to improved productivity.

Area Team Development (ATD) provides experts when a factory employee cannot complete his or her standard work in the time planned. Team members trained in the ATD process are called Skill Coaches. Skill Coaches provide support throughout each area to improve response time to problems. Andon boards and performance metrics are used for evaluating daily performance.

Cessna Aircraft Company

These commitments to Lean manufacturing are a major contributor to Cessna being the world's largest manufacturer of single-engine aircraft.

Sources: Interviews with Cessna executives, 2013.

Consignment inventory
An arrangement in which the supplier maintains title to the inventory until it is used.

- *Removal of in-transit inventory* by encouraging suppliers to locate nearby and provide frequent small shipments. The shorter the flow of material in the resource pipeline, the less inventory. Inventory can also be reduced through a technique known as *consignment*. Consignment inventory (see the *OM in Action* box, "Lean Production at Cessna Aircraft Company"), a variation of vendor-managed inventory (Chapter 11), means the supplier maintains the title to the inventory until it is used.
- *Obtain improved quality and reliability* through long-term commitments, communication, and cooperation.

Leading organizations view suppliers as extensions of their own organizations and expect suppliers to be fully committed to constant improvement. However, supplier concerns can be significant and must be addressed. These concerns include:

LO 16.3 *Identify* the concerns of suppliers when moving to supplier partnerships

1. *Diversification:* Suppliers may not want to tie themselves to long-term contracts with one customer. The suppliers' perception is that they reduce their risk if they have a variety of customers.
2. *Scheduling:* Many suppliers have little faith in the purchaser's ability to produce orders to a smooth, coordinated schedule.
3. *Lead time:* Engineering or specification changes can play havoc with JIT because of inadequate lead time for suppliers to implement the necessary changes.
4. *Quality:* Suppliers' capital budgets, processes, or technology may limit ability to respond to changes in product and quality.
5. *Lot sizes:* Suppliers may see frequent delivery in small lots as a way to transfer buyers' holding costs to suppliers.

As the foregoing concerns suggest, good supplier partnerships require a high degree of trust and respect by both supplier and purchaser—in a word, collaboration. Many firms establish this trust and collaborate very successfully. Two such firms are McKesson-General and Baxter International, who provide surgical supplies for hospitals on a JIT basis. They deliver prepackaged surgical supplies based on hospital operating schedules. Moreover, the surgical packages themselves are prepared so supplies are available in the sequence in which they will be used during surgery.

Lean Layout

Lean layouts reduce another kind of waste—movement. The movement of material on a factory floor (or paper in an office) does not add value. Consequently, managers want flexible layouts that reduce the movement of both people and material. Lean layouts place material directly in the location where needed. For instance, an assembly line should be designed with delivery points next to the line so material need not be delivered first to a receiving department

and then moved again. Toyota has gone one step further and places components in the chassis of each vehicle moving down the assembly line. This is not only convenient, but it also allows Toyota to save space and opens areas adjacent to the assembly line previously occupied by shelves. When a layout reduces distance, firms often save labor and space and may have the added bonus of eliminating potential areas for accumulation of unwanted inventory. Table 16.1 provides a list of Lean layout tactics.

TABLE 16.1

LEAN LAYOUT TACTICS
Build work cells for families of products
Include a large number of operations in a small area
Minimize distance
Design little space for inventory
Improve employee communication
Use *poka-yoke* devices
Build flexible or movable equipment
Cross-train workers to add flexibility

Distance Reduction Reducing distance is a major contribution of work cells, work centers, and focused factories (see Chapter 9). The days of long production lines and huge economic lots, with goods passing through monumental, single-operation machines, are gone. Now firms use work cells, often arranged in a U shape, containing several machines performing different operations. These work cells are often based on group technology codes (as discussed in Chapter 5). Group technology codes help identify components with similar characteristics so they can be grouped into families. Once families are identified, work cells are built for them. The result can be thought of as a small product-oriented facility where the "product" is actually a group of similar products—a family of products. The cells produce one good unit at a time, and ideally, they produce the units *only* after a customer orders them.

Increased Flexibility Modern work areas are designed so they can be easily rearranged to adapt to changes in volume and product changes. Almost nothing is bolted down. This concept of layout flexibility applies to both factory and office environments. Not only is furniture and equipment movable, but so are walls, computer connections, and telecommunications. Equipment is modular. Layout flexibility aids the changes that result from product *and* process improvements that are inevitable at a firm with a philosophy of continuous improvement.

Impact on Employees When layouts provide for sequential operations, feedback, including quality issues, can be immediate, allowing employees working together to tell each other about problems and opportunities for improvement. When workers produce units one at a time, they test each product or component at each subsequent production stage. Work processes with self-testing *poka-yoke* functions detect defects automatically. Before Lean, defective products were replaced from inventory. Because surplus inventory is not kept in Lean facilities, there are no such buffers. Employees learn that getting it right the first time is critical. Indeed, Lean layouts allow cross-trained employees to bring flexibility and efficiency to the work area, reducing defects. Defects are waste.

Reduced Space and Inventory Because Lean layouts reduce travel distance, they also reduce inventory. When there is little space, inventory travels less and must be moved in very small lots or even single units. Units are always moving because there is no storage. For instance, each month a Bank of America focused facility sorts 7 million checks, processes 5 million statements, and mails 190,000 customer statements. With a Lean layout, mail-processing time has been reduced by 33%, annual salary costs by tens of thousands of dollars, floor space by 50%, and in-process waiting lines by 75% to 90%. Storage, including shelves and drawers, has been removed.

Lean Inventory

Inventories in production and distribution systems often exist "just in case" something goes wrong. That is, they are used just in case some variation from the production plan occurs. The "extra" inventory is then used to cover variations or problems. Lean inventory tactics require "just in time," not "just in case." **Lean inventory** is the minimum inventory necessary to keep a perfect system running. With Lean inventory, the exact amount of goods arrives at the moment it is needed, not a minute before or a minute after. Some useful Lean inventory tactics are shown in Table 16.2 and discussed in more detail in the following sections.

TABLE 16.2

LEAN INVENTORY TACTICS
Use a pull system to move inventory
Reduce lot size
Develop just-in-time delivery systems with suppliers
Deliver directly to the point of use
Perform to schedule
Reduce setup time
Use group technology

Lean inventory
The minimum inventory necessary to keep a perfect system running.

Reduce Inventory and Variability Operations managers move toward Lean by first reducing inventory. The idea is to eliminate variability in the production system hidden by inventory. Reducing inventory uncovers the "rocks" in Figure 16.3(a) that represent the variability and problems currently being tolerated. With reduced inventory, management chips away at the exposed problems. After the lake is lowered, managers make additional cuts

STUDENT TIP
Accountants book inventory as an asset, but operations managers know it is a cost.

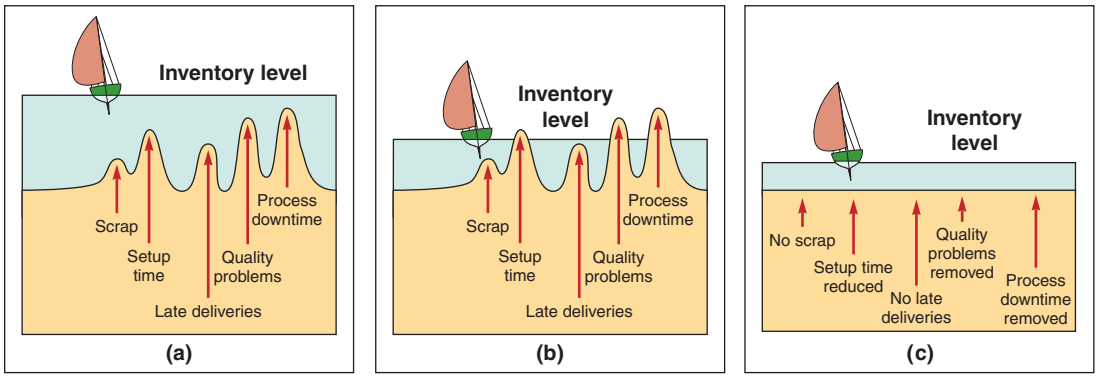


Figure **16.3**

High levels of inventory hide problems (a), but as we reduce inventory, problems are exposed (b), and finally after reducing inventory and removing problems, we have lower inventory, lower costs, and smooth sailing (c).

"Inventory is evil."
S. Shingo

Bob Daemmrich/CORBIS-NY

in inventory and continue to chip away at the next level of exposed problems [see Figure 16.3(b, c)]. Ultimately, there will be little inventory and few problems (variability).

Firms with technology-sensitive products estimate that the rapid product innovations can cost as much as $\frac{1}{2}\%$ to 2% of the values of inventory *each week*. Shigeo Shingo, codeveloper of the Toyota JIT system, says, "Inventory is evil." He is not far from the truth. If inventory itself is not evil, it hides evil at great cost.

Reduce Lot Sizes Lean also reduces waste by cutting the investment in inventory. A key to slashing inventory is to produce good product in small lot sizes. Reducing the size of batches can be a major help in reducing inventory and inventory costs. As we saw in Chapter 12, when inventory usage is constant, the average inventory level is the sum of the maximum inventory plus the minimum inventory divided by 2. Figure 16.4 shows that lowering the order size increases the number of orders, but drops inventory levels.

Ideally, in a Lean environment, order size is one and single units are being pulled from one adjacent process to another. More realistically, analysis of the process, transportation time, and physical attributes such as size of containers used for transport are considered when determining lot size. Such analysis typically results in a small lot size, but a lot size larger than one. Once a lot size has been determined, the EOQ production order quantity model can be modified to determine the desired setup time. We saw in Chapter 12 that the production order quantity model takes the form:

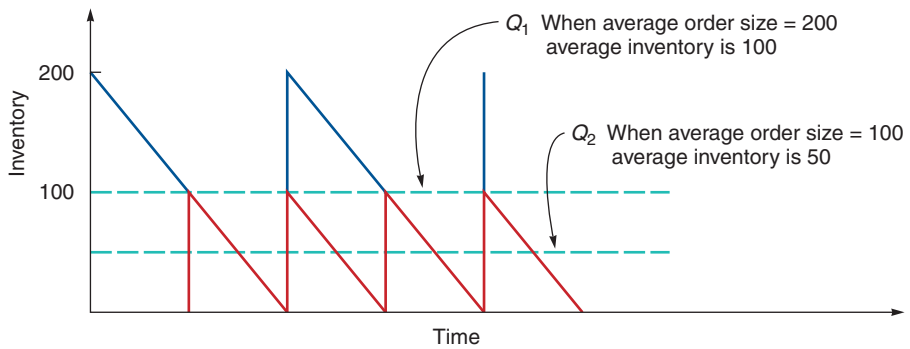
$$Q_p^* = \sqrt{\frac{2DS}{H[1 - (d/p)]}} \tag{16-1}$$

where D = Annual demand, S = Setup cost, H = Holding cost, d = Daily demand, p = Daily production

Figure **16.4**

Frequent Orders Reduce Average Inventory

A lower order size increases the number of orders and total ordering cost but reduces average inventory and total holding cost.



Example 1 shows how to determine the desired setup time.

Example 1

DETERMINING OPTIMAL SETUP TIME

Crate Furniture, Inc., a firm that produces rustic furniture, desires to move toward a reduced lot size. Crate Furniture's production analyst, Aleda Roth, determined that a 2-hour production cycle would be acceptable between two departments. Further, she concluded that a setup time that would accommodate the 2-hour cycle time should be achieved.

APPROACH ▶ Roth developed the following data and procedure to determine optimum setup time analytically:

D = Annual demand = 400,000 units
d = Daily demand = 400,000 per 250 days = 1,600 units per day
p = Daily production rate = 4,000 units per day
Q_p = EOQ desired = 400 (which is the 2-hour demand; that is, 1,600 per day per four 2-hour periods)
H = Holding cost = \$20 per unit per year
S = Setup cost (to be determined)

Hourly labor rate = \$30.00

LO 16.4 *Determine optimal setup time*

SOLUTION ▶ Roth determines that the cost and related time per setup should be:

$$Q_p = \sqrt{\frac{2DS}{H(1 - d/p)}}$$

$$Q_p^2 = \frac{2DS}{H(1 - d/p)}$$

$$S = \frac{(Q_p^2)(H)(1 - d/p)}{2D} \qquad (16\text{-}2)$$

$$= \frac{(400)^2(20)(1 - 1{,}600/4{,}000)}{2(400{,}000)} = \frac{(3{,}200{,}000)(0.6)}{800{,}000} = \$2.40$$

$$\begin{aligned}\text{Setup time} &= \$2.40/(\text{hourly labor rate})\\ &= \$2.40/(\$30 \text{ per hour})\\ &= 0.08 \text{ hour, or } 4.8 \text{ minutes}\end{aligned}$$

INSIGHT ▶ Now, rather than produce components in large lots, Crate Furniture can produce in a 2-hour cycle with the advantage of an inventory turnover of four *per day*.

LEARNING EXERCISE ▶ If labor cost goes to \$40 per hour, what should be the setup time? [Answer: 0.06 hours, or 3.6 minutes.]

RELATED PROBLEMS ▶ 16.1, 16.2, 16.3

Only two changes need to be made for small-lot material flow to work. First, material handling and work flow need to be improved. With short production cycles, there can be very little wait time. Improving material handling is usually easy and straightforward. The second change is more challenging, and that is a radical reduction in setup times. We discuss setup reduction next.

Reduce Setup Costs Both the quantity of inventory and the cost of holding it go down as the inventory-reorder quantity and the maximum inventory level drop. However, because inventory requires incurring an ordering or setup cost that is applied to the units produced, managers tend to purchase (or produce) large orders; the larger the order the less the cost to be absorbed by each unit. Consequently, the way to drive down lot sizes *and* reduce inventory cost is to reduce setup cost, which in turn lowers the optimum order size.

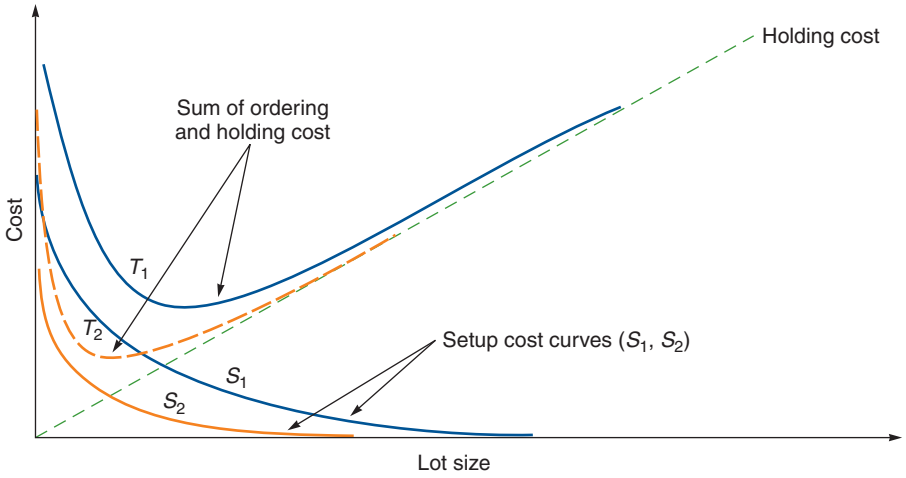
STUDENT TIP
Reduced lot sizes must be accompanied by reduced setup times.

The effect of reduced setup costs on total cost and lot size is shown in Figure 16.5. Moreover, smaller lot sizes hide fewer problems. In many environments, setup cost is highly correlated with setup time. In a manufacturing facility, setups usually require a substantial amount of preparation. Much of the preparation required by a setup can be done prior to shutting down

Figure 16.5

Lower Setup Costs Will Lower Total Cost

More frequent orders require reducing setup costs; otherwise, inventory costs will rise. As the setup costs are lowered (from S_1 to S_2), total inventory costs also fall (from T_1 to T_2).



the machine or process. Setup times can be reduced substantially, as shown in Figure 16.6. For example in one Kodak plant in Mexico, the setup time to change a bearing was reduced from 12 hours to 6 minutes! This is the kind of progress that is typical of world-class manufacturers.

Just as setup costs can be reduced at a machine in a factory, setup time can also be reduced during the process of getting the order ready in the office. Driving down factory setup time from hours to minutes does little good if orders are going to take weeks to process or "set up" in the office. This is exactly what happens in organizations that forget that Lean concepts have applications in offices as well as in the factory. Reducing setup time (and cost) is an excellent way to reduce inventory investment, improve productivity, and speed throughput.

Lean Scheduling

STUDENT TIP Effective scheduling is required for effective use of capital and personnel.

Effective schedules, communicated to those within the organization as well as to outside suppliers, support Lean. Better scheduling also improves the ability to meet customer orders, drives down inventory by allowing smaller lot sizes, and reduces work-in-process. For instance, many companies, such as Ford, now tie suppliers to their final assembly schedule. Ford communicates its schedules to bumper manufacturer Polycon Industries from the Ford production control system. The scheduling system describes the style and color of the bumper needed for each vehicle moving down the final assembly line. The scheduling system transmits the information to portable terminals carried by Polycon warehouse personnel, who load the bumpers onto conveyors leading to the loading dock. The bumpers are then trucked 50 miles to the Ford plant. Total time is 4 hours. However, as we saw in our opening *Global Company Profile*, Toyota has moved its bumper supplier *inside* the new Tundra plant; techniques such as this drive down delivery time even further.

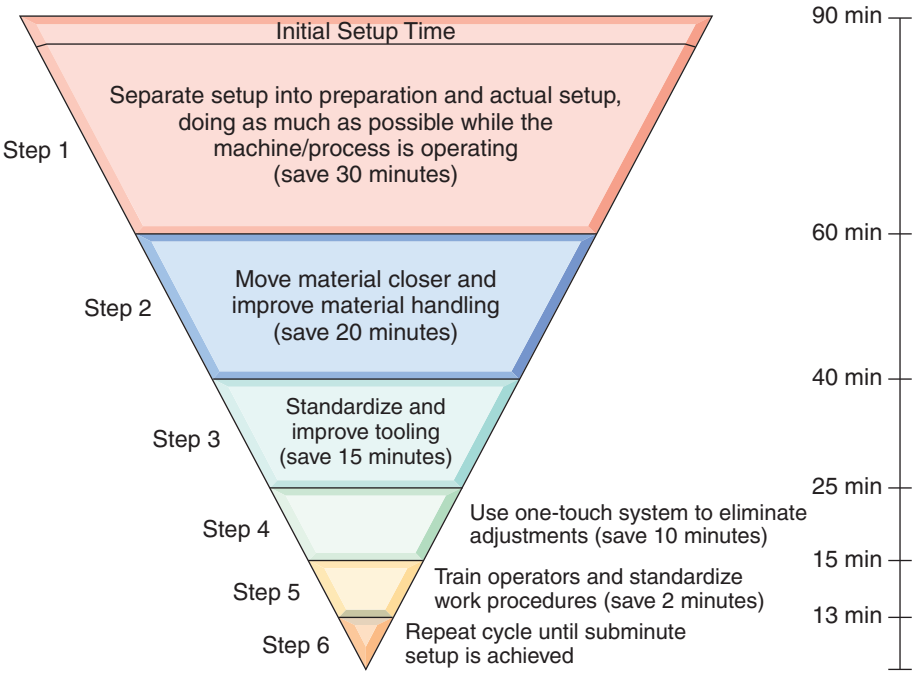


Figure 16.6

Steps for Reducing Setup Times

Reduced setup times are a major component of Lean.

Table 16.3 suggests several items that can contribute to achieving these goals, but two techniques (in addition to communicating schedules) are paramount. They are *level schedules* and *kanban*.

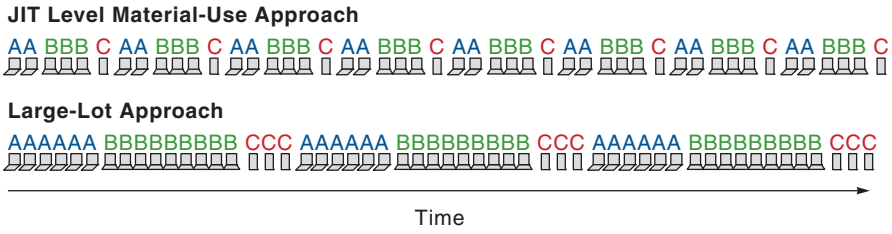


Figure 16.7

Scheduling Small Lots of Parts A, B, and C Increases Flexibility to Meet Customer Demand and Reduces Inventory

The Lean approach to scheduling, described as heijunka by the Japanese, produces just as many of each model per time period as the large-lot approach, provided setup times are lowered.

Level Schedules Level schedules process frequent small batches rather than a few large batches. Figure 16.7 contrasts a traditional large-lot approach using large batches with a level schedule using many small batches. The operations manager's task is to make and move small lots so the level schedule is economical. This requires success with the issues discussed in this chapter that allow small lots. As lots get smaller, the constraints may change and become increasingly challenging. At some point, processing a unit or two may not be feasible. The constraint may be the way units are sold and shipped (four to a carton), or an expensive paint changeover (on an automobile assembly line), or the proper number of units in a sterilizer (for a food-canning line).

The scheduler may find that *freezing*, that is holding a portion of the schedule near due dates constant, allows the production system to function and the schedule to be met. Operations managers expect the schedule to be achieved with no deviations.

Level schedules
Scheduling products so that each day's production meets the demand for that day.

TABLE 16.3

LEAN SCHEDULING TACTICS
Make level schedules
Use kanbans
Communicate schedules to suppliers
Freeze part of the schedule
Perform to schedule
Seek one-piece-make and one-piece-move
Eliminate waste
Produce in small lots
Each operation produces a perfect part

Kanban One way to achieve small lot sizes is to move inventory through the shop only as needed rather than *pushing* it on to the next workstation whether or not the personnel there are ready for it. As noted earlier, when inventory is moved only as needed, it is referred to as a *pull* system, and the ideal lot size is one. The Japanese call this system *kanban*. Kanbans allow arrivals at a work center to match (or nearly match) the processing time.

Kanban is a Japanese word for *card*. In their effort to reduce inventory, the Japanese use systems that "pull" inventory through work centers. They often use a "card" to signal the need for another container of material—hence the name *kanban.* The card is the authorization for the next container of material to be produced. Typically, a kanban signal exists for each container of items to be obtained. An order for the container is then initiated by each kanban and "pulled" from the producing department or supplier. A sequence of kanbans "pulls" the material through the plant.

Kanban
The Japanese word for *card*, which has come to mean "signal"; a kanban system moves parts through production via a "pull" from a signal.

The system has been modified in many facilities so that even though it is called a *kanban*, the card itself does not exist. In some cases, an empty position on the floor is sufficient indication that the next container is needed. In other cases, some sort of signal, such as a flag or rag (Figure 16.8), alerts that it is time for the next container.

LO 16.5 *Define* kanban

When there is visual contact between producer and user, the process works like this:

1. The user removes a standard-size container of parts from a small storage area, as shown in Figure 16.8.
2. The signal at the storage area is seen by the producing department as authorization to replenish the using department or storage area. Because there is an optimum lot size, the producing department may make several containers at a time.

A kanban system is similar to the resupply that occurs in your neighborhood supermarket: the customer buys; the stock clerk observes the shelf or receives notice from the end-of-day sales list and restocks. When the store's limited supply is depleted, a "pull" signal is sent to the warehouse, distributor, or manufacturer for resupply, usually that night. The complicating factor in a manufacturing firm is the time needed for actual manufacturing (production) to take place.

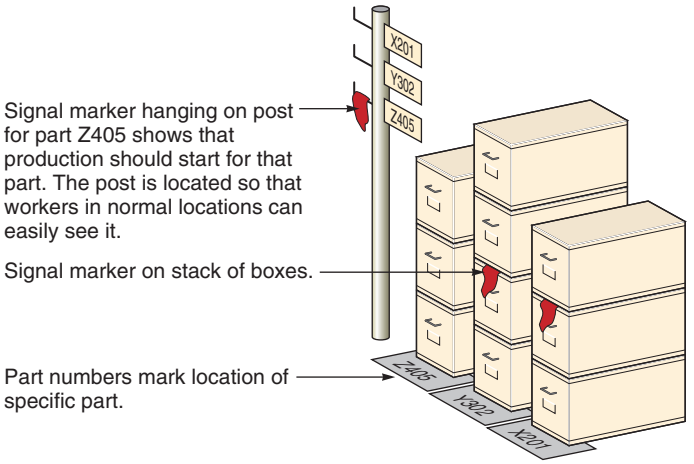


Figure 16.8

Diagram of Storage Area with Warning-Signal Marker


Donna Shader

A kanban need not be as formal as signal lights or empty carts. The cook in a fast-food restaurant knows that when six cars are in line, eight meat patties and six orders of french fries should be cooking.

Several additional points regarding kanbans may be helpful:

- When the producer and user are not in visual contact, a card can be used; otherwise, a light, flag, or empty spot on the floor may be adequate.
- Usually each card controls a specific quantity of parts, although multiple card systems are used if the work cell produces several components or if the lot size is different from the move size.
- The kanban cards provide a direct control (limit) on the amount of work-in-process between cells.

Determining the Number of Kanban Cards or Containers The number of kanban cards, or containers, sets the amount of authorized inventory. To determine the number of containers moving back and forth between the using area and the producing areas, management first sets the size of each container. This is done by computing the lot size, using a model such as the production order quantity model [discussed in Chapter 12 and shown again on page 644 in Equation (16-1)]. Setting the number of containers involves knowing: (1) lead time needed to produce a container of parts and (2) the amount of safety stock needed to account for variability or uncertainty in the system. The number of kanban cards is computed as follows:

LO 16.6 *Compute* the required number of kanbans

$$\text{Number of kanbans (containers)} = \frac{\text{Demand during lead time} + \text{Safety stock}}{\text{Size of container}} \tag{16-3}$$

Example 2 illustrates how to calculate the number of kanbans needed.

Example 2

DETERMINING THE NUMBER OF KANBAN CONTAINERS

Hobbs Bakery produces short runs of cakes that are shipped to grocery stores. The owner, Ken Hobbs, wants to try to reduce inventory by changing to a kanban system. He has developed the following data and asked you to finish the project.

$$\text{Production lead time} = \text{Wait time} + \text{Material handling time} + \text{Processing time} = 2 \text{ days}$$

$$\text{Daily demand} = 500 \text{ cakes}$$

$$\text{Safety stock} = \tfrac{1}{2} \text{ day}$$

$$\text{Container size (determined on a production order size EOQ basis)} = 250 \text{ cakes}$$

APPROACH ▶ Having determined that the EOQ size is 250, we then determine the number of kanbans (containers) needed.

SOLUTION ▶ Demand during lead time =

$$\text{Lead time} \times \text{Daily demand} = 2 \text{ days} \times 500 \text{ cakes} = 1{,}000$$

$$\text{Safety stock} = \tfrac{1}{2} \times \text{Daily demand} = 250$$

Number of kanbans (containers) needed =

$$\frac{\text{Demand during lead time} + \text{Safety stock}}{\text{Container size}} = \frac{1{,}000 + 250}{250} = 5$$

INSIGHT ▶ Once the reorder point is hit, five containers should be released.

LEARNING EXERCISE ▶ If lead time drops to 1 day, how many containers are needed? [Answer: 3.]

RELATED PROBLEMS ▶ 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 16.10 (16.11, 16.12 are available in MyOMLab)

Advantages of Kanban Containers are typically very small, usually a matter of a few hours' worth of production. Such a system requires tight schedules, with small quantities being produced several times a day. The process must run smoothly with little variability in quality or lead time because any shortage has an almost immediate impact on the entire system. Kanban places added emphasis on meeting schedules, reducing the time and cost required by setups, and economical material handling.

In-plant kanban systems often use standardized, reusable containers that protect the specific quantities to be moved. Such containers are also desirable in the supply chain. Standardized containers reduce weight and disposal costs, generate less wasted space, and require less labor to pack, unpack, and prepare items.

Lean Quality

STUDENT TIP
Good quality costs less.

There is no Lean without quality. And Lean's "pull" production, smaller batch sizes, and low inventory all enhance quality by exposing bad quality. Savings occur because scrap, rework, inventory investment, and poor product are no longer buried in inventory. This means fewer bad units are produced. In short, whereas inventory *hides* bad quality, Lean *exposes* it.

As Lean shrinks queues and lead time, it keeps evidence of errors fresh and limits the number of potential sources of error. In effect, Lean creates an early warning system for quality problems so that fewer bad units are produced and feedback is immediate. This advantage accrues both within the firm and with goods received from outside vendors.

In addition, better quality means fewer buffers are needed, and therefore, a better, easier-to-maintain inventory system can exist. Often the purpose of keeping inventory is to protect against unreliable quality. But, when consistent quality exists, Lean firms can reduce all costs associated with inventory. Table 16.4 suggests some tactics for quality in a Lean environment.

TABLE 16.4

LEAN QUALITY TACTICS
Use statistical process control
Empower employees
Build fail-safe methods (poka-yoke, checklists, etc.)
Expose poor quality with small lots
Provide immediate feedback

Lean and the Toyota Production System

Toyota Motor's Eiji Toyoda and Taiichi Ohno are given credit for the Toyota Production System (TPS; see the *Global Company Profile* that opens this chapter). Three components of TPS are *continuous improvement*, *respect for people*, and *standard work practice*, which are now considered an integral part of Lean.

Continuous Improvement

Continuous improvement under TPS means building an organizational culture and instilling in its people a value system stressing that processes can be improved—indeed, that improvement is an integral part of every employee's job. This process is formalized in TPS by **kaizen**, the Japanese word for change for the good, or what is more generally known as *continuous improvement*. Kaizen is often implemented by a kaizen event. A **kaizen event** occurs when members of a work cell group or team meet to develop innovative ways to immediately implement improvements in the work area or process. In application, kaizen means making a multitude of small or incremental changes as one seeks elusive perfection. (See the *OM in Action* box, "Toyota's New Challenge.") Instilling the mantra of continuous improvement begins at personnel recruiting and continues through extensive and continuing training. One of the reasons continuous improvement works at Toyota, we should note, is because of another core value at Toyota, Toyota's respect for people.

Kaizen
A focus on continuous improvement.

Kaizen event
Members of a work cell or team meet to develop improvements in the process.

Respect for People

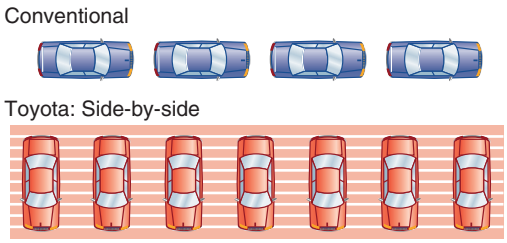
STUDENT TIP
Respect for people brings the entire person to work.

Toyota, like other Lean organizations, recruits, trains, and treats people as knowledge workers. Aided by aggressive cross-training and few job classifications, Lean firms engage the mental as well as physical capacities of employees in the challenging task of improving operations. Employees are empowered. They are empowered not only to make improvements, but also to stop machines and processes when quality problems exist. Indeed, empowered employees are an integral part of Lean. This means that those tasks that have traditionally been assigned to staff are moved to employees. Toyota recognizes that employees know more about their jobs than anyone else. Lean firms respect employees by giving them the opportunity to enrich both their jobs and their lives.

OM in Action Toyota's New Challenge

With the generally high value of the yen, making a profit on cars built in Japan but sold in foreign markets is a challenge. As a result, Honda and Nissan are moving plants overseas, closer to customers. But Toyota, despite marginal profit on cars produced for export, is maintaining its current Japanese capacity. Toyota, which led the way with JIT and the TPS, is doubling down on its manufacturing prowess and continuous improvement. For an organization that traditionally does things slowly and step-by-step, the changes are radical. With its first new plant in Japan in 18 years, Toyota believes it can once again set new production benchmarks. It is drastically reforming its production processes in a number of ways:

- The assembly line has cars sitting side-by-side, rather than bumper-to-bumper, shrinking the length of the line by 35% and requiring fewer steps by workers.
- Instead of having car chassis dangling from overhead conveyors, they are perched on raised platforms, reducing heating and cooling costs by 40%.



- Retooling permits faster changeovers, allowing for shorter product runs of components, supporting level scheduling.
- The assembly line uses quiet friction rollers with fewer moving parts, requiring less maintenance than conventional lines and reducing worker fatigue.

These TPS innovations, efficient production with small lot sizes, rapid changeover, level scheduling, half the workers, and half the square footage, are being duplicated in Toyota's new plant in Blue Springs, Mississippi.

Sources: Forbes (July 29, 2012); *Automotive News* (February, 2011); and *The Wall Street Journal* (November 29, 2011).

Bernd Weissbrod/dpa/picture-alliance/Newscom

This Porsche assembly line, like most other Lean facilities, empowers employees so they can stop the entire production line, what the Japanese call *jidoka*, if any quality problems are spotted.

Processes and Standard Work Practice

Building effective and efficient processes requires establishing what Toyota calls standard work practices. The underlying principles are:

- Work is completely specified as to content, sequence, timing, and outcome; this is fundamental to a good process.
- Supplier connections for both internal and external customers are direct, specifying personnel, methods, timing, and quantity.
- Material and service flows are simple and directed to a specific person or machine.
- Process improvements are made only after rigorous analysis at the lowest possible level in the organization.

Lean requires that activities, connections, and flows include built-in tests (or poka-yokes) to signal problems. When a problem or defect occurs, production is stopped. Japanese call the practice of stopping production because of a defect, *jidoka*. The dual focus on (1) education and training of employees and (2) the responsiveness of the system to problems make the seemingly rigid system flexible and adaptable. The result is continuous improvement.

Lean Organizations

STUDENT TIP Lean drives out non-value-added activities.

Lean organizations understand the customer and the customer's expectations. Moreover, Lean organizations have functional areas that communicate and collaborate to verify that customer expectations are not only understood, but also met efficiently. This means identifying and delivering the customer's value expectation by implementing the tools of Lean throughout the organization.

Building a Lean Organization

Building Lean organizations is difficult, requiring exceptional leadership. Such leaders imbue the organization not just with the tools of Lean, but with a *culture* of continuous improvement. Building such a culture requires open communication and destroying isolated functional

disciplines that act as independent "silos." There is no substitute for open two-way communication that fosters effective and efficient processes. Such an organizational culture will have a demonstrated respect for people and a management willing to fully understand how and where the work is performed. Lean firms sometimes use the Japanese term **Gemba** or **Gemba walk** to refer to going to where the work is actually performed.

Gemba or Gemba walk
Going to where the work is actually performed.

Building organizational cultures that foster ongoing improvement and that accept the constant change and improvement that makes improvement habitual is a challenge. However, such organizations exist. They understand the customer and drive out activities that do not add value in the eyes of the customer. They include industry leaders such as United Parcel Service, Alaska Airlines, and, of course, Toyota. Even traditionally idiosyncratic organizations such as hospitals (see the *OM in Action* box, "Lean Delivers the Medicine") find improved productivity with Lean operations. Lean operations adopt a philosophy of minimizing waste by striving for perfection through continuous learning, creativity, and teamwork. They tend to share the following attributes:

VIDEO 16.1
Lean Operations at Alaska Airlines

- *Respect and develop employees* by improving job design, providing constant training, instilling commitment, and building teamwork.
- *Empower employees* with jobs that are made challenging by pushing responsibility to the lowest level possible.
- *Develop worker flexibility* through cross-training and reducing job classifications.
- *Build processes* that destroy variability by helping employees produce a perfect product every time.
- *Develop collaborative partnerships with suppliers*, helping them not only to understand the needs of the ultimate customer, but also to accept responsibility for satisfying those needs.
- *Eliminate waste by performing only value-added activities.* Material handling, inspection, inventory, travel time, wasted space, and rework are targets, as they do not add value.

LO 16.7 *Identify* six attributes of Lean organizations

Success requires leadership as well as the full commitment and involvement of managers, employees, and suppliers. The rewards that Lean producers reap are spectacular. Lean producers often become benchmark performers.

OM in Action Lean Delivers the Medicine

Using kaizen techniques straight out of Lean, a team of employees at San Francisco General Hospital target and then analyze a particular area within the hospital for improvement. Hospitals today are focusing on throughput and quality in the belief that excelling on these measures will drive down costs and push up patient satisfaction. Doctors and nurses now work together in teams that immerse themselves in a weeklong kaizen event. These events generate plans that make specific improvements in flow, quality, costs, or the patients' experience.

One recent kaizen event focused on the number of minutes it takes from the moment a patient is wheeled into the operating room to when the first incision is made. A team spent a week coming up with ways to whittle 10 minutes off this "prep" time. Every minute saved reduces labor cost and opens up critical facilities. Another kaizen event targeted the Urgent Care Center, dropping the average wait from 5 hours down to 2.5, primarily by adding an on-site X-ray machine instead of requiring patients to walk 15 minutes to the main radiology department. Similarly, wait times in the Surgical Clinic dropped from 2.5 hours to 70 minutes. The operating room now uses a *5S* protocol and has implemented *Standard Work* for the preoperation process.

As hospitals focus on improving medical quality and patient satisfaction, they are exposed to some Japanese terms associated with Lean, many of which do not have a direct English translation: **Gemba,** the place where work is actually performed; **Hansei,** a period of critical self-reflection; **Heijunka,** a level production schedule that provides balance and smooths day-to-day variation; **Jidoka,** using both human intelligence and technology to stop a process at the first sign of a potential problem; **Kaizen,** continuous improvement; and **Muda,** anything that consumes resources, but provides no value.


Franck Boston/Fotolia

Lean systems are increasingly being adopted by hospitals as they try to reduce costs while improving quality and increasing patient satisfaction—and as San Francisco General has demonstrated, Lean techniques are working.

Sources: San Francisco Chronicle (Oct. 14, 2013) and *San Francisco General Hospital & Trauma Center Annual Report*, 2012–2013.

Lean Sustainability

Lean and sustainability are two sides of the same coin. Both seek to maximize resource and economic efficiency. However, if Lean focuses on only the immediate process and system, then managers may miss the sustainability issues beyond the firm. As we discussed in Supplement 5, sustainability requires examining the systems in which the firm and its stakeholders operate. When this is done, both Lean and sustainability achieve higher levels of performance.

Lean drives out waste because waste adds nothing for the customer. Sustainability drives out waste because waste is both expensive and has an adverse effect on the environment. Driving out waste is the common ground of Lean sustainability.

STUDENT TIP Lean began in factories, but is now also used in services throughout the world.

Lean in Services

The features of Lean apply to services—from hospitals to amusement parks and airlines—directly influencing the customers' received value. The Lean attributes of respect for people, efficient processes with rigorous standard practices that drive out waste, and a focus on continuous improvement are pervasive vehicles for consistently generating value for all stakeholders. If there is any change in focus of Lean between manufacturing and services, it may be that the high level of customer interaction places added emphasis on enabling people through training, motivation, and empowerment to contribute to their fullest. However, in addition to the customer interaction aspect of services, here are some specific applications of Lean applied to suppliers, layout, inventory, and scheduling in the service sector.

LO 16.8 *Explain* how Lean applies to services

Suppliers Virtually every restaurant deals with its suppliers on a JIT basis. Those that do not are usually unsuccessful. The waste is too evident—food spoils, and customers complain, get sick, and may die. Similarly, JIT is basic to the financial sector that processes your deposits, withdrawals, and brokerage activities on a JIT basis. That is the industry standard.

Layouts Lean layouts are required in restaurant kitchens, where cold food must be served cold and hot food hot. McDonald's, for example, has reconfigured its kitchen layout, at great expense, to drive seconds out of the production process, thereby speeding delivery to customers. With the new process, McDonald's can produce made-to-order hamburgers in 45 seconds. Layouts also make a difference at Alaska Airline's baggage claim, where customers expect their bags in 20 minutes or less.

Inventory Stockbrokers drive inventory down to nearly zero every day. Most sell and buy orders occur on an immediate basis because an unexecuted sell or buy order is not acceptable to the client. A broker may be in serious trouble if left holding an unexecuted trade. Similarly, McDonald's reduces inventory waste by maintaining a time-stamped finished-goods inventory of only a few minutes; after that, it is thrown away. Hospitals, such as Arnold Palmer (described in this chapter's *Video Case Study*), manage JIT inventory and low safety stocks for many items. For instance, critical supplies such as pharmaceuticals may be held to low levels by developing community networks as backup. In this manner, if one pharmacy runs out of a needed drug, another member of the network can supply it until the next day's shipment arrives.

VIDEO 16.2 JIT at Arnold Palmer Hospital

Scheduling Airlines must adjust to fluctuations in customer demand. But rather than adjusting by changes in inventory, demand is satisfied by personnel availability. Through elaborate scheduling, personnel show up just in time to cover peaks in customer demand. In other words, rather than "things" being inventoried, personnel are scheduled. At a salon, the focus is only slightly different: prompt service is assured by scheduling both the *customer* and the staff. At McDonald's and Walmart, scheduling of personnel is down to 15-minute increments, based on precise forecasting of demand. Notice that in these organizations scheduling is a key ingredient of Lean. Excellent forecasts drive those schedules. Such forecasts may be very elaborate, with seasonal, daily, and even hourly components in the case of the airline ticket counter (holiday sales, flight time, etc.), seasonal and weekly components at the salon (holidays and Fridays create special problems), and down to a few minutes (to respond to the daily meal cycle) at McDonald's.

To deliver goods and services to customers under continuously changing demand, suppliers need to be reliable, inventories low, cycle times short, and schedules nimble. Lean engages and empowers employees to create and deliver the customer's perception of value, eliminating whatever does not contribute to this goal. Lean techniques are widely used in both goods-producing and service-producing firms; they just look different.

Summary

Lean operations, including JIT and TPS, focuses on continuous improvement to eliminate waste. Because waste is found in anything that does not add value, organizations that implement these techniques are adding value more efficiently than other firms. The expectation of lean firms is that empowered employees work with committed management to build systems that respond to customers with ever-increasing efficiency and higher quality.

Key Terms

Lean operations (p. 638)
Just-in-time (JIT) (p. 638)
Toyota Production System (TPS) (p. 638)
Seven wastes (p. 638)
5Ss (p. 639)
Variability (p. 639)
Throughput (p. 640)
Manufacturing cycle time (p. 640)
Pull system (p. 640)
Supplier partnerships (p. 640)
Consignment inventory (p. 642)
Lean inventory (p. 643)
Level schedules (p. 647)
Kanban (p. 647)
Kaizen (p. 649)
Kaizen event (p. 649)
Gemba or Gemba walk (p. 651)

Ethical Dilemma

In this Lean operations world, in an effort to lower handling costs, speed delivery, and reduce inventory, retailers are forcing their suppliers to do more and more in the way of preparing their merchandise for their cross-docking warehouses, shipment to specific stores, and shelf presentation. Your company, a small manufacturer of aquarium decorations, is in a tough position. First, Mega-Mart wanted you to develop bar-code technology, then special packaging, then small individual shipments bar coded for each store. (This way when the merchandise hits the warehouse, it is cross-docked immediately to the truck destined for that store, and upon arrival the merchandise is ready for shelf placement.) And now Mega-Mart wants you to develop RFID—immediately. Mega-Mart has made it clear that suppliers that cannot keep up with the technology will be dropped.

Earlier, when you didn't have the expertise for bar codes, you had to borrow money and hire an outside firm to do the development, purchase the technology, and train your shipping clerk. Then, meeting the special packaging requirement drove you into a loss for several months, resulting in a loss for last year. Now it appears that the RFID request is impossible. Your business, under the best of conditions, is marginally profitable, and the bank may not be willing to bail you out again. Over the years, Mega-Mart has slowly become your major customer and without it, you are probably out of business. What are the ethical issues, and what do you do?

Discussion Questions

1. What is a Lean producer?
2. What is JIT?
3. What is TPS?
4. What is level scheduling?
5. JIT attempts to remove delays, which do not add value. How, then, does JIT cope with weather and its impact on crop harvest and transportation times?
6. What are three ways in which Lean and quality are related?
7. What is kaizen, and what is a kaizen event?
8. What are the characteristics of supplier partnerships with respect to suppliers?
9. Discuss how the Japanese word for *card* has application in the study of JIT.
10. Standardized, reusable containers have obvious benefits for shipping. What is the purpose of these devices within the plant?
11. Does Lean production work in the service sector? Provide an example.
12. Which Lean techniques work in both the manufacturing *and* service sectors?

Solved Problem

Virtual Office Hours help is available in MyOMLab.

SOLVED PROBLEM 16.1

Krupp Refrigeration, Inc., is trying to reduce inventory and wants you to install a kanban system for compressors on one of its assembly lines. Determine the size of the kanban and the number of kanbans (containers) needed.

Setup cost = \$10
Annual holding cost per compressor = \$100
Daily production = 200 compressors
Annual usage = 25,000 (50 weeks × 5 days each × daily usage of 100 compressors)
Lead time = 3 days
Safety stock = $\frac{1}{2}$ day's production of compressors

SOLUTION

First, we must determine kanban container size. To do this, we determine the production order quantity [see discussion in Chapter 12 or Equation (16-1)], which determines the kanban size:

$$Q_p^* = \sqrt{\frac{2DS}{H\left(1-\frac{d}{p}\right)}} = \sqrt{\frac{2(25{,}000)(10)}{H\left(1-\frac{d}{p}\right)}} = \sqrt{\frac{500{,}000}{100\left(1-\frac{100}{200}\right)}} = \sqrt{\frac{500{,}000}{50}}$$

$$= \sqrt{10{,}000} = 100 \text{ compressors. So the production order size and the size of the kanban container} = 100.$$

Then we determine the number of kanbans:

$$\text{Demand during lead time} = 300 \ (= 3 \text{ days} \times \text{daily usage of } 100)$$

$$\text{Safety stock} = 100 \ (= \tfrac{1}{2} \times \text{daily production of } 200)$$

$$\text{Number of kanbans} = \frac{\text{Demand during lead time} + \text{Safety stock}}{\text{Size of container}}$$

$$= \frac{300 + 100}{100} = \frac{400}{100} = 4 \text{ containers}$$

Problems

Note: PX means the problem may be solved with POM for Windows and/or Excel OM.

Problems 16.1–16.12 relate to Lean and Just-in-Time

••• **16.1** Carol Cagle has a repetitive manufacturing plant producing trailer hitches in Arlington, Texas. The plant has an average inventory turnover of only 12 times per year. She has therefore determined that she will reduce her component lot sizes. She has developed the following data for one component, the safety chain clip:

Annual demand = 31,200 units
Daily demand = 120 units
Daily production (in 8 hours) = 960 units
Desired lot size (1 hour of production) = 120 units
Holding cost per unit per year = $12
Setup labor cost per hour = $20

How many minutes of setup time should she have her plant manager aim for regarding this component?

••• **16.2** Given the following information about a product at Michael Gibson's firm, what is the appropriate setup time?

Annual demand = 39,000 units
Daily demand = 150 units
Daily production = 1,000 units
Desired lot size = 150 units
Holding cost per unit per year = $10
Setup labor cost per hour = $40

••• **16.3** Rick Wing has a repetitive manufacturing plant producing automobile steering wheels. Use the following data to prepare for a reduced lot size. The firm uses a work year of 305 days.

Annual demand for steering wheels	30,500
Daily demand	100
Daily production (8 hours)	800
Desired lot size (2 hours of production)	200
Holding cost per unit per year	$10

a) What is the setup cost, based on the desired lot size?
b) What is the setup time, based on $40 per hour setup labor?

• **16.4** Hartley Electronics, Inc., in Nashville, produces short runs of custom airwave scanners for the defense industry. The owner, Janet Hartley, has asked you to reduce inventory by introducing a kanban system. After several hours of analysis, you develop the following data for scanner connectors used in one work cell. How many kanbans do you need for this connector?

Daily demand	1,000 connectors
Lead time	2 days
Safety stock	$\frac{1}{2}$ day
Kanban size	500 connectors

• **16.5** Tej Dhakar's company wants to establish kanbans to feed a newly established work cell. The following data have been provided. How many kanbans are needed?

Daily demand	250 units
Lead time	$\frac{1}{2}$ day
Safety stock	$\frac{1}{4}$ day
Kanban size	50 units

•• **16.6** Pauline Found Manufacturing, Inc., is moving to kanbans to support its telephone switching-board assembly lines. Determine the size of the kanban for subassemblies and the number of kanbans needed.

Setup cost = $30
Annual holding cost = $120 per subassembly
Daily production = 20 subassemblies
Annual usage = 2,500 (50 weeks × 5 days each × daily usage of 10 subassemblies)
Lead time = 16 days
Safety stock = 4 days' production of subassemblies PX

•• **16.7** Maggie Moylan Motorcycle Corp. uses kanbans to support its transmission assembly line. Determine the size of the kanban for the mainshaft assembly and the number of kanbans needed.

Setup cost = $20
Annual holding cost of mainshaft assembly = $250 per unit
Daily production = 300 mainshafts
Annual usage = 20,000 (= 50 weeks × 5 days each × daily usage of 80 mainshafts)
Lead time = 3 days
Safety stock = $\frac{1}{2}$ day's production of mainshafts

• **16.8** Discount-Mart, a major East Coast retailer, wants to determine the economic order quantity (see Chapter 12 for EOQ formulas) for its halogen lamps. It currently buys all halogen lamps from Specialty Lighting Manufacturers in Atlanta. Annual demand is 2,000 lamps, ordering cost per order is $30, and annual carrying cost per lamp is $12.

a) What is the EOQ?
b) What are the total annual costs of holding and ordering (managing) this inventory?
c) How many orders should Discount-Mart place with Specialty Lighting per year?

••• **16.9** Discount-Mart (see Problem 16.8), as part of its new Lean program, has signed a long-term contract with Specialty Lighting and will place orders electronically for its halogen lamps. Ordering costs will drop to $.50 per order, but Discount-Mart also reassessed its carrying costs and raised them to $20 per lamp.
a) What is the new economic order quantity?
b) How many orders will now be placed?
c) What is the total annual cost of managing the inventory with this policy?

•• **16.10** How do your answers to Problems 16.8 and 16.9 provide insight into a collaborative purchasing strategy?

Additional problems **16.11–16.12** *are available in* MyOMLab.

CASE STUDIES

Lean Operations at Alaska Airlines

Video Case

Alaska Airlines operates in a land of rugged beauty, crystal clear lakes, spectacular glaciers, majestic mountains, and bright blue skies. But equally awesome is its operating performance. Alaska Airlines consistently provides the industry's number one overall ranking and best on-time performance. A key ingredient of this excellent performance is Alaska Airlines' Lean initiative.

With an aggressive implementation of Lean, Ben Minicucci, Executive VP for Operations, is finding ever-increasing levels of performance. He pushes this initiative throughout the company with: (1) a focus on continuous improvement, (2) metrics that measure performance against targets, and (3) making performance relevant to Alaska Airlines' empowered employees.

With leadership training that includes a strong focus on participative management, Minicucci has created a seven-person Lean Department. The department provides extensive training in Lean via one-week courses, participative workshops, and two-week classes that train employees to become a Six Sigma Green Belt. Some employees even pursue the next step, Black Belt certification.

A huge part of any airline's operations is fuel cost, but capital utilization and much of the remaining cost is dependent upon ground equipment and crews that handle aircraft turnaround and maintenance, in-flight services, and customer service.

As John Ladner, Director of Seattle Airport Operations, has observed, "Lean eliminates waste, exposes non-standard work, and is forcing a focus on variations in documented best practices and work time."

Lean is now part of the Alaska Airlines corporate culture, with some 60 ongoing projects. Kaizen events (called "Accelerated Improvement Workshops" at Alaska Airlines), Gemba Walks (called "waste walks" by Alaska Airlines), and 5S are now a part of everyday conversation at Alaska Airlines. Lean projects have included:

- Applying 5S to identify aircraft ground equipment and its location on the tarmac.
- Improving preparation for and synchronization of the arrival and departure sequences; time to open the front door after arrival has been reduced from 4.5 to 1 min.
- Redefining the disconnect procedure for tow bars used to "push back" aircraft at departure time; planes now depart 2–3 minutes faster.
- Revising the deicing process, meaning less time for the plane to be on the tarmac.
- Improving pilot staffing, making Alaska's pilot productivity the highest in the industry. Every 1% improvement in productivity leads to a $5 million savings on a recurring basis. Alaska Airlines has achieved a 7% productivity improvement over the last five years.

Alaska Airlines

Another current Lean project is passenger unloading and loading. Lean instructor Allison Fletcher calls this "the most unique project I have worked on." One exciting aspect of deplaning is Alaska's solar-powered "switchback" staircase for unloading passengers through the rear door (see photo). Alaska is saving two minutes, or nearly 17%, off previous unloading time with this new process. Alaska Airlines' Lean culture has made it a leader in the industry.

Discussion Questions*

1. What are the key ingredients of Lean, as identified at Alaska Airlines?
2. As an initial phase of a kaizen event, discuss the many ways passengers can be loaded and unloaded from airplanes.
3. Document the research that is being done on the aircraft passenger-loading problem.

* You may wish to view the video that accompanies this case before addressing these questions.

JIT at Arnold Palmer Hospital

Video Case 

Orlando's Arnold Palmer Hospital, founded in 1989, specializes in treatment of women and children and is renowned for its high-quality rankings (top 10% of 2000 benchmarked hospitals), its labor and delivery volume (more than 14,000 births per year), and its neonatal intensive care unit (one of the highest survival rates in the nation). But quality medical practices and high patient satisfaction require costly inventory—some $30 million per year and thousands of SKUs.* With pressure on medical care to manage and reduce costs, Arnold Palmer Hospital has turned toward controlling its inventory with just-in-time (JIT) techniques.

Within the hospital, for example, drugs are now distributed at the nursing stations via dispensing machines (almost like vending machines) that electronically track patient usage and post the related charge to each patient. Each night, based on patient demand and prescriptions written by doctors, the dispensing stations are refilled.

To address JIT issues externally, Arnold Palmer Hospital turned to a major distribution partner, McKesson General Medical, which as a first-tier supplier provides the hospital with about one-quarter of all its medical/surgical inventory. McKesson supplies sponges, basins, towels, Mayo stand covers, syringes, and hundreds of other medical/surgical items. To ensure coordinated daily delivery of inventory purchased from McKesson, an account executive has been assigned to the hospital on a full-time basis, as well as two other individuals who address customer service and product issues. The result has been a drop in Central Supply average daily inventory from $400,000 to $114,000 since JIT.

JIT success has also been achieved in the area of *custom surgical packs*. Custom surgical packs are the sterile coverings, disposable plastic trays, gauze, and the like, specialized to each type of surgical procedure. Arnold Palmer Hospital uses 10 different custom packs for various surgical procedures. "Over 50,000 packs are used each year, for a total cost of about $1.5 million," says George DeLong, head of Supply-Chain Management.

The packs are not only delivered in a JIT manner, but packed that way as well. That is, they are packed in the reverse order they are used so each item comes out of the pack in the sequence it is needed. The packs are bulky, are expensive, and must remain sterile. Reducing the inventory and handling while maintaining an ensured sterile supply for scheduled surgeries presents a challenge to hospitals.

Here is how the supply chain works: Custom packs are *assembled* by a packing company with *components supplied* primarily from manufacturers selected by the hospital, and *delivered* by McKesson from its local warehouse. Arnold Palmer Hospital works with its own surgical staff (through the Medical Economics Outcome Committee) to identify and standardize the custom packs to reduce the number of custom pack SKUs. With this integrated system, pack safety stock inventory has been cut to one day.

The procedure to drive the custom surgical pack JIT system begins with a "pull" from the doctors' daily surgical schedule. Then, Arnold Palmer Hospital initiates an electronic order to McKesson between 1:00 and 2:00 P.M. daily. At 4:00 A.M. the next day, McKesson delivers the packs. Hospital personnel arrive at 7:00 A.M. and stock the shelves for scheduled surgeries. McKesson then reorders from the packing company, which in turn "pulls" necessary inventory for the quantity of packs needed from the manufacturers.

Arnold Palmer Hospital's JIT system reduces inventory investment, expensive traditional ordering, and bulky storage and supports quality with a sterile delivery.

Discussion Questions**

1. What do you recommend be done when an error is found in a pack as it is opened for an operation?
2. How might the procedure for custom surgical packs described here be improved?
3. When discussing JIT in services, the text notes that suppliers, layout, inventory, and scheduling are all used. Provide an example of each of these at Arnold Palmer Hospital.
4. When a doctor proposes a new surgical procedure, how do you recommend the SKU for a new custom pack be entered into the hospital's supply-chain system?

*SKU = stock keeping unit

**You may wish to view the video that accompanies this case before answering these questions.

- **Additional Case Studies:** Visit MyOMLab for these case studies:
  JIT after a Catastrophe: How Caterpillar responded after a tornado tore apart its Oxford plant.
  Mutual Insurance Company of Iowa: Applying JIT in an insurance office.

Endnote

1. The term 5S comes from the Japanese words seiri (*sort* and clear out), seiton (*straighten* and configure), seiso (*scrub* and clean up), seiketsu (maintain *sanitation* and cleanliness of self and workplace), and shitsuke (*self-discipline and standardization* of these practices).

Chapter 16 *Rapid* Review

Main Heading	Review Material	MyOMLab
LEAN OPERATIONS (pp. 638–640)	■ **Lean operations**—Eliminates waste through continuous improvement and focus on exactly what the customer wants. ■ **Just-in-time (JIT)**—Continuous and forced problem solving via a focus on throughput and reduced inventory. ■ **Toyota Production System (TPS)**—Focus on continuous improvement, respect for people, and standard work practices. *When implemented as a comprehensive manufacturing strategy, Lean, JIT, and TPS systems sustain competitive advantage and result in increased overall returns.* ■ **Seven wastes**—Overproduction, queues, transportation, inventory, motion, overprocessing, and defective product. ■ **5Ss**—A Lean production checklist: sort, simplify, shine, standardize, and sustain. U.S. managers often add two additional *S*s to the 5 original ones: *safety* and *support/maintenance*. ■ **Variability**—Any deviation from the optimum process that delivers perfect product on time, every time. Both JIT and inventory reduction are effective tools for identifying causes of variability. ■ **Throughput**—The rate at which units move through a process. ■ **Manufacturing cycle time**—The time between the arrival of raw materials and the shipping of finished products. ■ **Pull system**—A concept that results in material being produced only when requested and moved to where it is needed just as it is needed. Pull systems use signals to request production and delivery from supplying stations to stations that have production capacity available.	Concept Questions: 1.1–1.4
LEAN AND JUST-IN-TIME (pp. 640–649)	■ **Supplier partnerships**—Suppliers and purchasers work together to remove waste and drive down costs for mutual benefit. Some specific goals of supplier partnerships are *removal of unnecessary activities*, *removal of in-plant inventory, removal of in-transit inventory,* and *obtain improved quality and reliability*. ■ **Consignment inventory**—An arrangement in which the supplier maintains title to the inventory until it is used. Concerns of suppliers in suppler partnerships include (1) *diversification*, (2) *scheduling*, (3) *lead time*, (4) *quality*, and (5) *lot sizes*. *Lean layout tactics* include building work cells for families of products, including a large number of operations in a small area, minimizing distance, designing little space for inventory, improving employee communication, using poka-yoke devices, building flexible or movable equipment, and cross-training workers to add flexibility. ■ **Lean inventory**—The minimum inventory necessary to keep a perfect system running. The idea behind JIT is to eliminate inventory that hides variability in the production system. *Lean inventory tactics* include using a pull system to move inventory, reducing lot size, developing just-in-time delivery systems with suppliers, delivering directly to the point of use, performing to schedule, reducing setup time, and using group technology. $$Q_p^* = \sqrt{\frac{2DS}{H[1 - (d/p)]}} \quad (16\text{-}1)$$ Using Equation (16-1), for a given desired lot size, Q, we can solve for the optimal setup cost, S: $$S = \frac{(Q^2)(H)(1 - d/p)}{2D} \quad (16\text{-}2)$$ *Lean scheduling tactics* include communicate schedules to suppliers, make level schedules, freeze part of the schedule, perform to schedule, seek one-piece-make and one-piece-move, eliminate waste, produce in small lots, use kanbans, and make each operation produce a perfect part. ■ **Level schedules**—Scheduling products so that each day's production meets the demand for that day. ■ **Kanban**—The Japanese word for *card*, which has come to mean "signal"; a kanban system moves parts through production via a "pull" from a signal. $$\text{Number of kanbans (containers)} = \frac{\text{Demand during lead time} + \text{Safety stock}}{\text{Size of container}} \quad (16\text{-}3)$$ *Lean quality*—whereas inventory *hides* bad quality, Lean immediately *exposes* it. Lean quality tactics include using statistical process control, empowering employees, building fail-safe methods (poka-yoke, checklists, etc.), exposing poor quality with small lots, and providing immediate feedback.	Concept Questions: 2.1–2.4 Problems: 16.1–16.3 Problems: 16.4–16.9, 16.11, 16.12 Virtual Office Hours for Solved Problem: 16.1

Chapter 16 *Rapid* Review *continued*

Main Heading	Review Material	MyOMLab
LEAN AND THE TOYOTA PRODUCTION SYSTEM (pp. 649–650)	■ **Kaizen**—A focus on continuous improvement. ■ **Kaizen event**—Members of a work cell or team meet to develop improvements in the process. Toyota recruits, trains, and treats people as knowledge workers. They are empowered. TPS employs aggressive cross-training and few job classifications.	Concept Questions: 3.1–3.4
LEAN ORGANIZATIONS (pp. 650–652)	Lean operations tend to share the following attributes: *respect and develop employees* by improving job design, providing constant training, instilling commitment, and building teamwork; *empower employees* by pushing responsibility to the lowest level possible; *develop worker flexibility* through cross-training and reducing job classifications; *build processes* that destroy variability; *develop collaborative partnerships with suppliers* to help them accept responsibility for satisfying end customer needs; and *eliminate waste by performing only value-added activities.* ■ **Gemba** or **Gemba walk**—Going to where the work is actually performed.	Concept Questions: 4.1–4.4 **VIDEO 16.1** Lean Operations at Alaska Airlines
LEAN IN SERVICES (p. 652)	The features of Lean operations apply to services just as they do in other sectors. Forecasts in services may be very elaborate, with seasonal, daily, hourly, or even shorter components.	Concept Questions: 5.1–5.4 **VIDEO 16.2** JIT at Arnold Palmer Hospital

Self Test

■ **Before taking the self-test,** refer to the learning objectives listed at the beginning of the chapter and the key terms listed at the end of the chapter.

LO 16.1 Match Lean Operations, JIT, and TPS with the concepts shown below:
- **a)** Continuous improvement and a focus on exactly what the customer wants, and when.
- **b)** Supply the customer with exactly what the customer wants when the customer wants it, without waste, through continuous improvement.
- **c)** Emphasis on continuous improvement, respect for people, and standard work practices.

LO 16.2 Define the seven wastes and the 5Ss. The seven wastes are _____, _____, _____, _____, _____. _____, and _____, and the 5Ss are _____, _____, _____, _____, and _____.

LO 16.3 Concerns of suppliers when moving to Supplier Partnerships include:
- **a)** small lots sometimes seeming economically prohibitive.
- **b)** realistic quality demands.
- **c)** changes without adequate lead time.
- **d)** erratic schedules.
- **e)** all of the above.

LO 16.4 What is the formula for optimal setup time?
- **a)** $\sqrt{2DQ/[H(1 - d/p)]}$
- **b)** $\sqrt{Q^2H(1 - d/p)/(2D)}$
- **c)** $QH(1 - d/p)/(2D)$
- **d)** $Q^2H(1 - d/p)/(2D)$
- **e)** $H(1 - d/p)$

LO 16.5 Kanban is the Japanese word for:
- **a)** car.
- **b)** pull.
- **c)** card.
- **d)** continuous improvement.
- **e)** level schedule.

LO 16.6 The required number of kanbans equals:
- **a)** 1.
- **b)** Demand during lead time / Q
- **c)** Size of container.
- **d)** Demand during lead time.
- **e)** Demand during lead time + Safety stock / Size of container

LO 16.7 The six attributes of Lean organizations are: _____, _____, _____, _____, _____, and _____.

LO 16.8 Lean applies to services:
- **a)** only in rare instances.
- **b)** except in terms of the supply chain.
- **c)** except in terms of employee issues.
- **d)** except in terms of both supply chain issues and employee issues.
- **e)** just as it applies to manufacturing.

Answers: LO 16.1. Lean = a, JIT = b, TPS = c; LO 16.2. overproduction, queues, transportation, inventory, motion, overprocessing, defective product; sort, simplify, shine, standardize, sustain; LO 16.3. e; LO 16.4. d; LO 16.5. c; LO 16.6. e; LO 16.7. respect and develop people, empower employees, develop worker flexibility, build excellent processes, develop collaborative partnerships with suppliers, eliminate waste; LO 16.8. e.