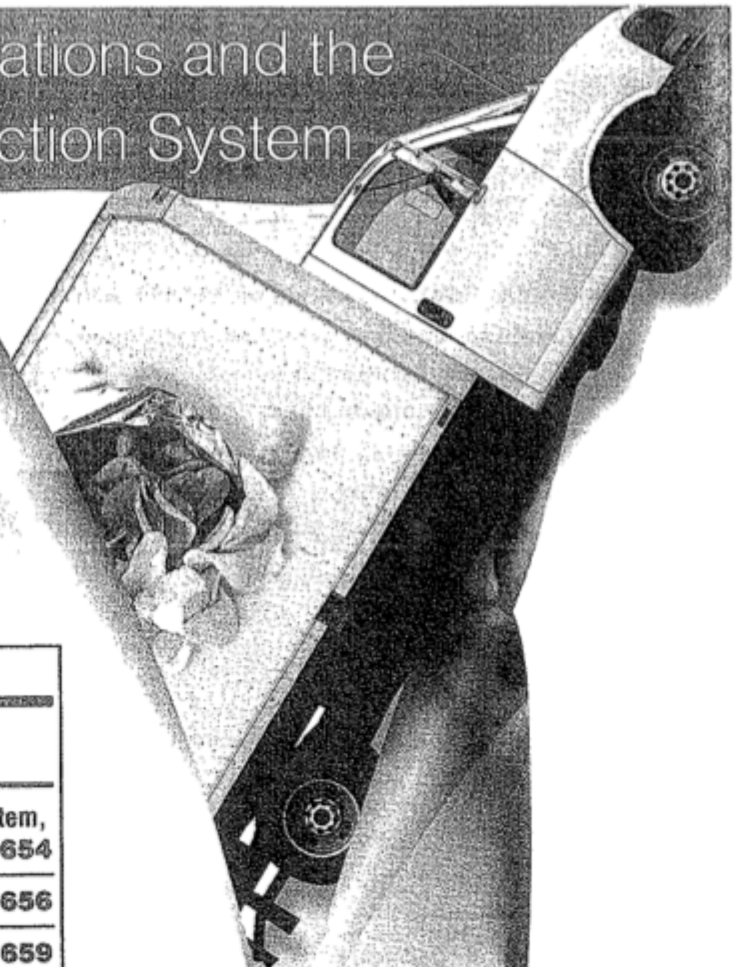
16 JIT, Lean Operations and the Toyota Production System



Chapter Outline

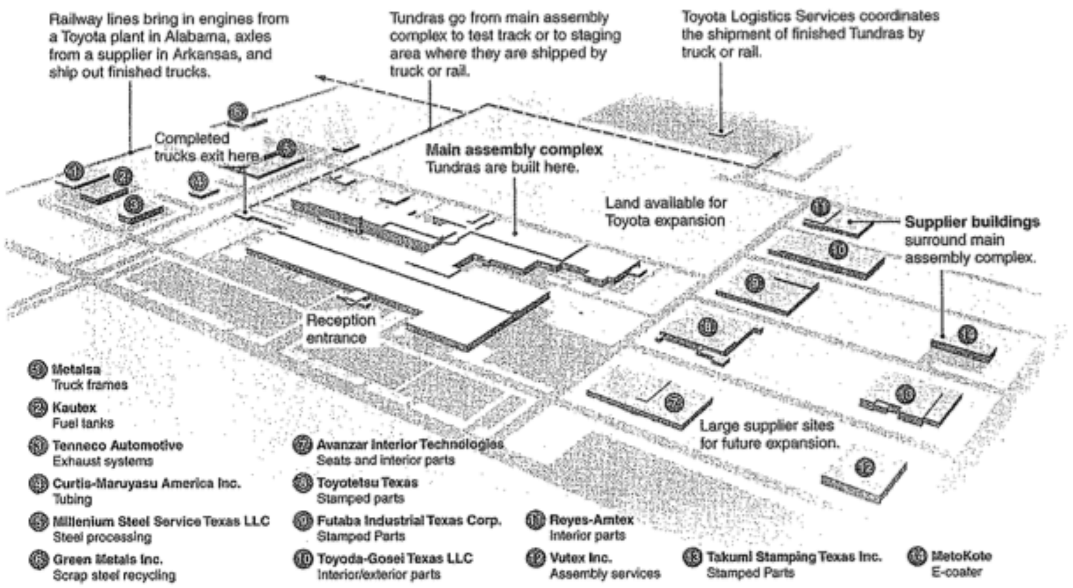
10 OM Strategy Decisions

- Design of Goods and Services
- Managing Quality
- Process Strategy
- Location Strategies
- Layout Strategies
- Human Resources
- Supply-Chain Management
- Inventory Management
  - Independent Demand
  - Dependent Demand
  - JIT and Lean Operations
- Scheduling
- Maintenance

ACHIEVING COMPETITIVE ADVANTAGE WITH LEAN OPERATIONS AT TOYOTA MOTOR CORPORATION

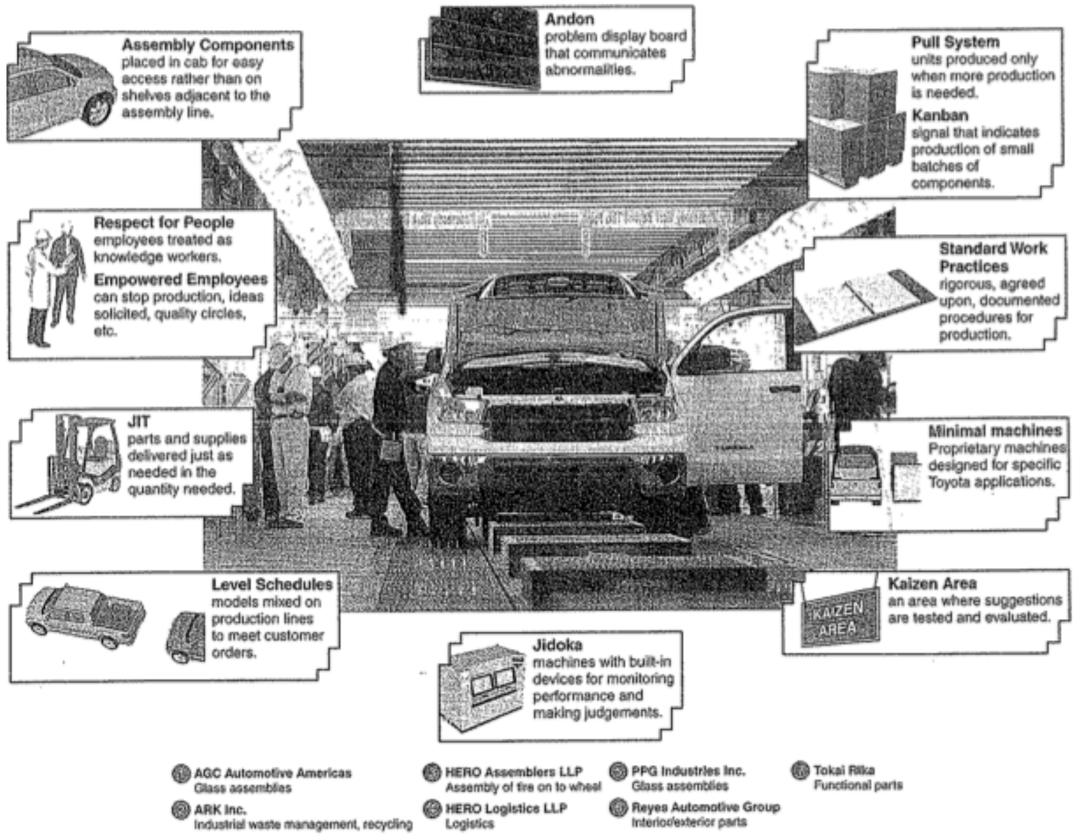
Toyota Motor Corporation, with annual sales of over 9 million cars and trucks, is the largest vehicle manufacturer in the world. Two techniques, just-in-time (JIT) and the Toyota Production System (TPS), have been instrumental in this post-WWII growth. Toyota, with a wide range of vehicles, competes 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 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 continued 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 has no slack. When excess inventory is eliminated, quality, layout, scheduling, and supplier issues 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 facilities, machines, and people are brought



14 Suppliers outside the main plant

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



7 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.

together, adding 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 latest implementation of TPS and JIT is present at its new San Antonio plant, the largest Toyota land site for an automobile assembly plant in the U.S. Interestingly, despite its annual production capability of 200,000 Tundra pick-up trucks, 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 sub-assemblies. 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 new 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. JIT, TPS, and lean operations work—and they provide a competitive advantage at Toyota Motor Corporation.

Chapter 16 Learning Objectives

AUTHOR COMMENT World-class firms everywhere are using these three techniques.

JUST-IN-TIME, THE TOYOTA PRODUCTION SYSTEM, AND LEAN OPERATIONS

LO1: Define just-in-time, TPS, and lean operations

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.

Lean operations Eliminates waste through a focus on exactly what the customer wants.

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 JIT, TPS, and lean operations as approaches to continuing improvement that drive out waste and lead to world-class organizations.

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. **Lean operations** supplies 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. When implemented as a comprehensive manufacturing strategy, JIT, TPS, and lean systems sustain competitive advantage and result in increased overall returns.

If there is any distinction between JIT, TPS, and lean operations, it is that:

- JIT emphasizes forced problem solving.
- TPS emphasizes employee learning and empowerment in an assembly-line environment.
- Lean operations emphasize understanding the customer.

However, in practice, there is little difference, and the terms are often used interchangeably. Leading organizations use the approaches and techniques that make sense for them. In this chapter, we use the term *lean operations* to encompass all of the related approaches and techniques.

Regardless of the label put on operations improvement, good production systems require that managers address three issues that are pervasive and fundamental to operations management: eliminate waste, remove variability, and improve throughput. We first introduce these three issues and then discuss the major attributes of JIT, TPS, and lean operations. Finally, we look at lean operations applied to services.

LO2: Define the seven wastes and the 5Ss

Eliminate Waste

Traditional producers have limited goals—accepting, for instance, the production of some defective parts and some inventory. 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. Inventory of any kind is usually a waste.
- *Queues:* Idle time, storage, and waiting are wastes (they add no value).
- *Transportation:* Moving material between plants or between work centers and handling 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 a waste.

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, 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:

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 non-value items and remove them. Getting rid of these items makes space available and usually improves work flow.
- *Simplify/straighten:* Arrange and use methods analysis tools (see Chapter 7 and Chapter 10) to improve work flow 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.
- *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 above five activities.
- *Support/maintenance:* Reduce variability, unplanned downtime, and costs. Integrate daily shine tasks with preventive maintenance.

The Ss provide a vehicle for continuous improvement with which all 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 so that assets are released 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 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 perfect product on time, every time.

- Poor production processes that allow employees and suppliers to produce improper quantities or late or non-conforming units
- Unknown customer demands
- Incomplete or inaccurate drawings, specifications, and bills of material

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

Both JIT and inventory reduction are effective tools for identifying causes of variability. The precise timing of JIT makes variability evident, just as reducing inventory exposes variability. The removal of variability allows managers to move good materials on schedule, add value at each step of the production process, drive down costs, and win orders.

Improve Throughput

Throughput
The time required to move orders through the production process, from receipt to delivery.

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 a measure (in units or time) that it takes to move an order from receipt to delivery. Each minute products remain on the books, costs accumulate and competitive advantage is lost. 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 Northern Telecom now has materials pulled directly from qualified suppliers to the assembly line. This effort has reduced a segment of Northern's 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.

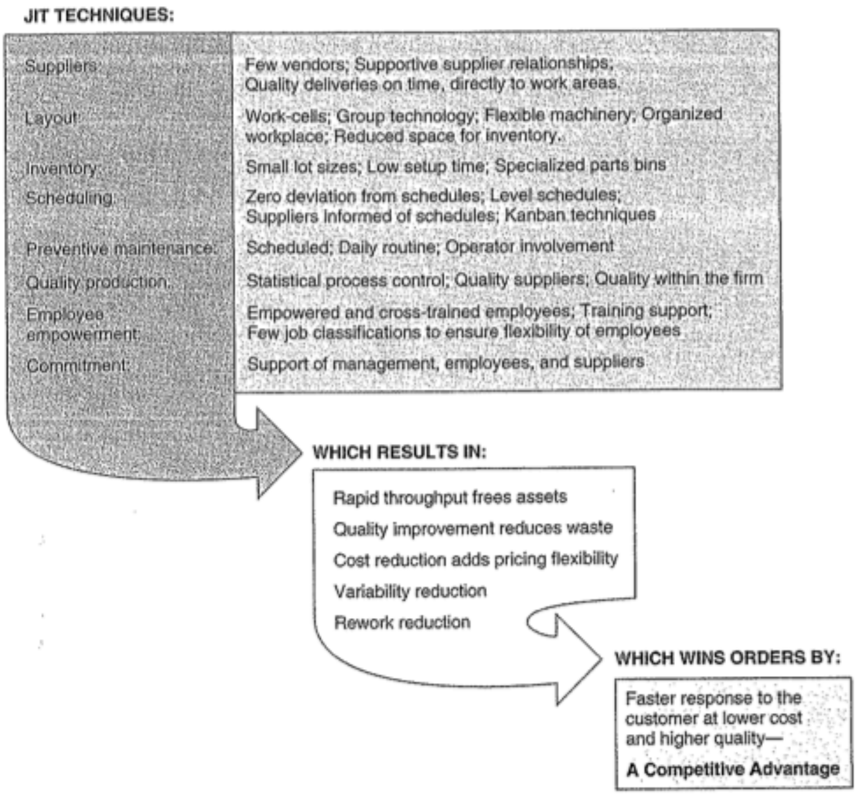
A technique for increasing throughput is a pull system. A **pull system** *pulls* a unit to where it is needed just as it is needed. Pull systems are a standard tool of JIT systems. Pull systems use signals to request production and delivery from supplying stations to stations that have production capacity 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 JIT. 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.

AUTHOR COMMENT JIT places added demands on performance, but that is why it pays off.

JUST-IN-TIME (JIT)

With its forced problem solving via a focus on rapid throughput and reduced inventory, JIT provides a powerful strategy for improving operations. With JIT, 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. By driving out waste and delay in this manner, JIT reduces costs associated with excess inventory, cuts variability and waste, and improves throughput. JIT is a key ingredient of lean operations and is particularly helpful in supporting strategies of rapid response and low cost.

Many services have adopted JIT techniques as a normal part of their business. Restaurants like Olive Garden and Red Lobster 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.



◄ **FIGURE 16.1**
JIT Contributes to Competitive Advantage

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.

Effective JIT requires a meaningful buyer–supplier partnership.

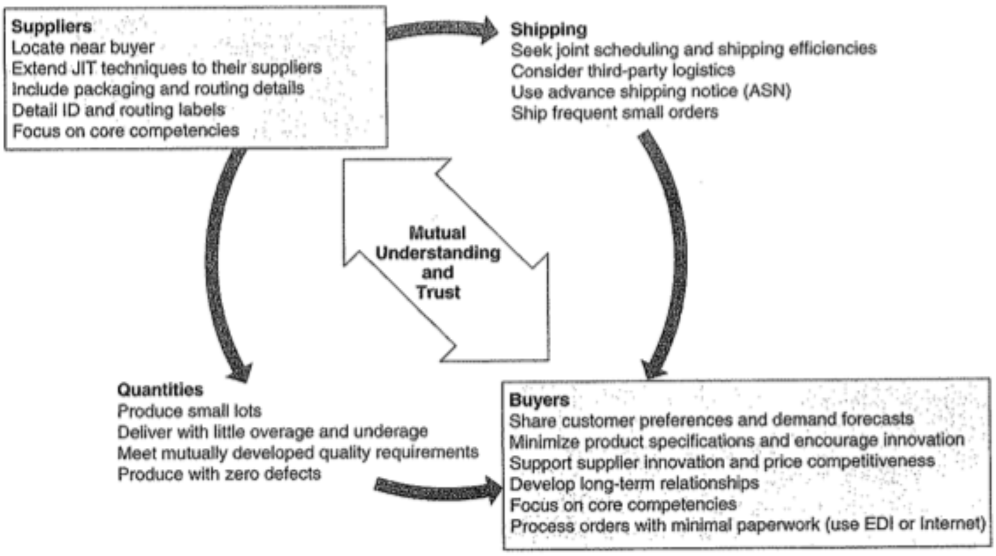
JIT Partnerships

A **JIT partnership** exists when a supplier and a purchaser work together with open communication and a goal of removing waste and driving down costs. Close relationships and trust are critical to the success of JIT. Figure 16.2 shows the characteristics of JIT partnerships. Some specific goals of JIT partnerships are:

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

- *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.
- *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"), a variation of vendor-managed inventory (Chapter 11), means the supplier maintains the title to the inventory until it is used. For instance, an assembly plant may find a hardware supplier that is willing to locate its warehouse where the user currently has its stockroom. In this manner, when hardware is needed, it is no farther than the stockroom. Schedule and production information must be shared with the consignment supplier, or inventory holding costs will just be transferred from the buyer to the supplier, with no net cost reduction. Another option is to have the supplier ship to other, perhaps smaller, purchasers from the "stockroom."
- *Obtain improved quality and reliability* through long-term commitments, communication, and cooperation.

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



▲ FIGURE 16.2 **Characteristics of JIT Partnerships**

Leading organizations view suppliers as extensions of their own organizations and expect suppliers to be fully committed to improvement. Such relationships require a high degree of respect by both supplier and purchaser. Supplier concerns can be significant; Harley-Davidson, for example, initially had difficulty implementing JIT because supplier issues outweighed the perceived benefits.

LO3: Explain JIT partnerships

Concerns of Suppliers

Successful JIT partnerships require that supplier concerns be addressed. These concerns include:

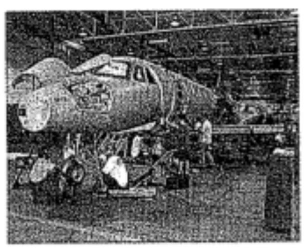
1. *Diversification:* Suppliers may not want to tie themselves to long-term contracts with one customer. The suppliers' perception is that they reduce their risk if they have a variety of customers.
2. *Scheduling:* Many suppliers have little faith in the purchaser's ability to produce orders to a smooth, coordinated schedule.

OM in Action ▶ Lean Production at Cessna Aircraft

When Cessna Aircraft opened its new plant in Independence, Kansas, it saw the opportunity to switch from a craftwork mentality producing small single-engine planes to a lean manufacturing system. In doing so, Cessna adopted three lean practices.

First, Cessna set up consignment- and vendor-managed inventories with several of its suppliers. Blanket purchase orders allow Honeywell, for example, to maintain a 30-day supply of avionic parts onsite. Other vendors were encouraged to use a nearby warehouse to keep parts that could then be delivered daily to the production line.

Second, Cessna managers committed to cross-training, in which team members learn the duties of other team members and can shift across assembly lines as needed. To develop these technical skills, Cessna brought in 60 retired assembly-line workers to mentor and teach new employees. Employees were taught to work as a team and to assume responsibility for their team's quality.



Third, the company used group technology and manufacturing cells to move away from a batch process that resulted in large inventories and unsold planes. Now, Cessna pulls product through its plant only when a specific order is placed.

These commitments to manufacturing efficiency are part of the lean operations that has made Cessna the world's largest manufacturer of single-engine aircraft.

Sources: www.cessna.com (2007); *Strategic Finance* (November 2002): 32; *Purchasing* (September 4, 2003): 25–30; and *Fortune* (May 1, 2000): 1222B.

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.

JIT LAYOUT

JIT 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. JIT 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. This is what VF Corporation's Wrangler Division in Greensboro, North Carolina, did; denim is now delivered directly to the line. Toyota has gone one step farther and places hardware and components in the chassis of each vehicle moving down the assembly line. This is not only convenient, but it 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 JIT layout tactics.

▼ TABLE 16.1
JIT 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 we can group them 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 cells are designed so they can be easily rearranged to adapt to changes in volume, product improvements, or even new designs. Almost nothing in these new departments is bolted down. This same concept of layout flexibility applies to office environments. Not only is most office furniture and equipment movable, but so are office walls, computer connections, and telecommunications. Equipment is modular. Layout flexibility aids the changes that result from product *and* process improvements that are inevitable with a philosophy of continuous improvement.

Impact on Employees

JIT layouts allow cross-trained employees to bring flexibility and efficiency to the work cell. Employees working together can tell each other about problems and opportunities for improvement. When layouts provide for sequential operations, feedback can be immediate. Defects are waste. When workers produce units one at a time, they test each product or component at each subsequent production stage. Machines in work cells with self-testing poka-yoke functions detect defects and stop automatically when they occur. Before JIT, defective products were replaced from inventory. Because surplus inventory is not kept in JIT facilities, there are no such buffers. Getting it right the first time is critical.

Reduced Space and Inventory

Because JIT layouts reduce travel distance, they also reduce inventory by removing space for inventory. When there is little space, inventory must be moved in very small lots or even single units. Units are always moving because there is no storage. For instance, each month Security

Pacific Corporation's focused facility sorts 7 million checks, processes 5 million statements, and mails 190,000 customer statements. With a JIT layout, mail processing time has been reduced by 33%, salary costs by tens of thousands of dollars per year, floor space by 50%, and in-process waiting lines by 75% to 90%. Storage, including shelves and drawers, has been removed.

AUTHOR COMMENT
Accountants book inventory as an asset, but operations managers know it is costly.

JIT 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. Effective inventory tactics require "just in time," not "just in case." **Just-in-time inventory** is the minimum inventory necessary to keep a perfect system running. With just-in-time inventory, the exact amount of goods arrives at the moment it is needed, not a minute before or a minute after. Some useful JIT inventory tactics are shown in Table 16.2 and discussed in more detail in the following sections.

Just-in-time inventory
The minimum inventory necessary to keep a perfect system running.

"Inventory is evil."
S. Shingo

Reduce Inventory and Variability

Operations managers move toward JIT by first removing 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 in inventory and continue to chip away at the next level of exposed problems (see Figure 16.3[b,c]). Ultimately, there will be virtually no inventory and no problems (variability).

Dell estimates that the rapid changes in technology costs $\frac{1}{2}$% to 2% of its inventory's value *each week*. Shigeo Shingo, co-developer 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.

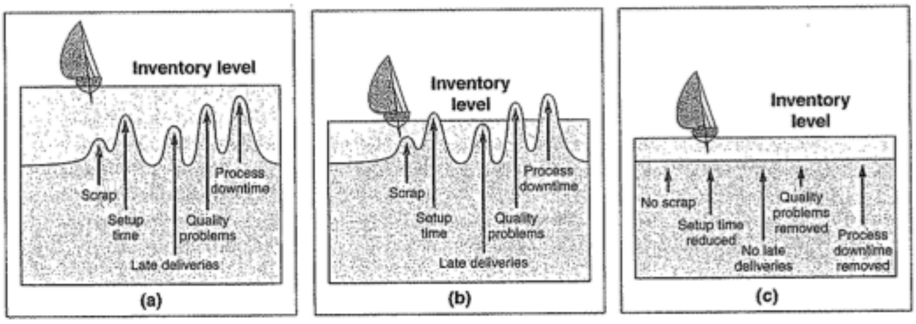
▼ TABLE 16.2
JIT Inventory Tactics

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

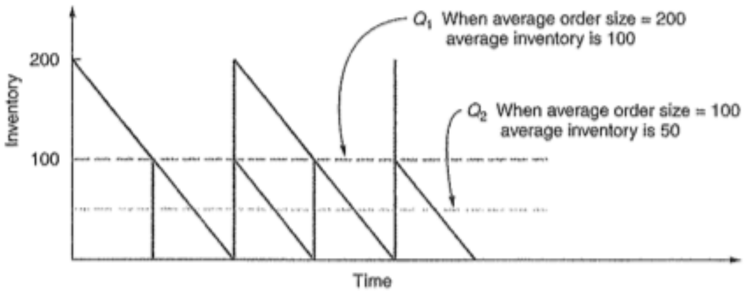
Reduce Lot Sizes

Just-in-time has also come to mean elimination of waste by reducing investment in inventory. The key to JIT is producing 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 JIT 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 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



▲ 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).**



◁ **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.

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:

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

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

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 = 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)

SOLUTION ▶ Roth determines that the cost, on an hourly basis, of setting up equipment is \$30. Further, she computes that the setup cost per setup should be:

LO4: Determine optimal setup time

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

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

$$S = \frac{(Q^2)(H)(1 - d/p)}{2D} \tag{16-2}$$

$$= \frac{(400)^2(20)(1 - 1{,}600/4{,}000)}{2(400{,}000)}$$

$$= \frac{(3{,}200{,}000)(0.6)}{800{,}000} = \$2.40$$

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

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: .06 hour, or 3.6 minutes.]

RELATED PROBLEMS ▶ 16.8, 16.9, 16.10

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.

AUTHOR COMMENT Reduced lot sizes must be accompanied by reduced setup times.

Reduce Setup Costs

Both 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 must be applied to the units produced, managers tend to purchase (or produce) large orders. With large orders, each unit purchased or ordered absorbs only a small part of the setup cost. Consequently, the way to drive down lot sizes *and* reduce average inventory is to reduce setup cost, which in turn lowers the optimum order size.

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 the machine or process. Setup times can be reduced substantially, as shown in Figure 16.6. For instance, in Kodak's Guadalajara, Mexico, plant a team reduced the setup time to change a bearing 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. It does little good to drive down factory setup time from hours to minutes if orders are going to take 2 weeks to process or "set up" in the office. This is exactly what happens in organizations that forget that JIT concepts have applications in offices as well as in the factory. Reducing setup time (and cost) is an excellent way to reduce inventory investment and to improve productivity.

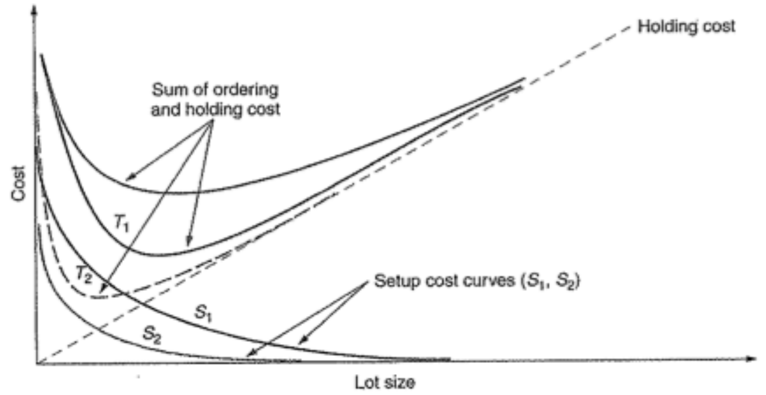
AUTHOR COMMENT Effective scheduling is required for effective use of capital and personnel.

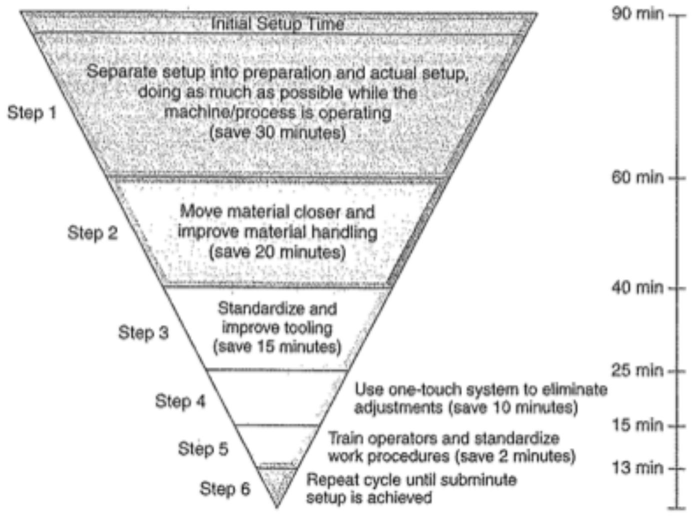
JIT SCHEDULING

Effective schedules, communicated both within the organization and to outside suppliers, support JIT. 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, Ford

▶ 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).





◁ **FIGURE 16.6**
Steps for Reducing Setup Times
Reduced setup times are a major JIT component.

▼ **TABLE 16.3**
JIT Scheduling Tactics

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
Make each operation produce a perfect part

Motor Company now ties some suppliers to its final assembly schedule. Ford communicates its schedules to bumper manufacturer Polycon Industries from the Ford Oakville 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 seat supplier inside the new Tundra plant; this has driven down delivery time even further.

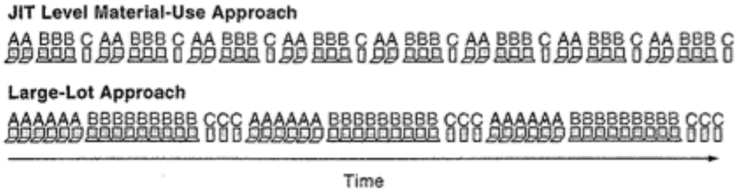
Table 16.3 suggests several items that can contribute to achieving these goals, but two techniques (in addition to communicating schedules) are paramount. They are *level schedules* and *kanban*.

Level Schedules

Level schedules process frequent small batches rather than a few large batches. Because this technique schedules many small lots that are always changing, it has on occasion been called "jelly bean" scheduling. Figure 16.7 contrasts a traditional large-lot approach using large batches with a JIT 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

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

▼ **FIGURE 16.7 Scheduling Small Lots of Parts A, B, and C Increases Flexibility to Meet Customer Demand and Reduces Inventory**
The JIT approach to scheduling produces just as many of each model per time period as the large-lot approach, provided that setup times are lowered.



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* the portion of the schedule closest to due dates allows the production system to function and the schedule to be met. Freezing means not allowing changes to be part of the schedule. Operations managers expect the schedule to be achieved with no deviations from the schedule.

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

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

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.

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.

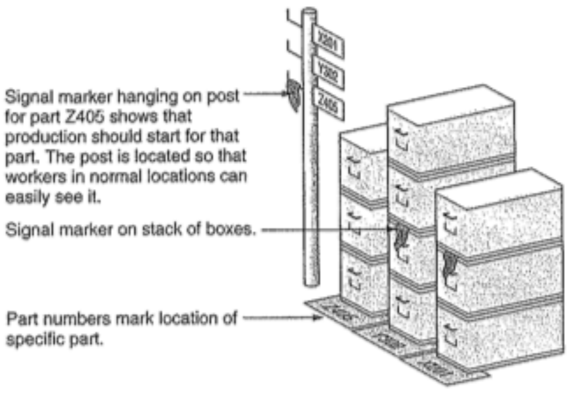
When there is visual contact between producer and user, the process works like this:

LO5: Define kanban

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.

Figure 16.9 shows how a kanban works, pulling units as needed from production. This 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 limited supply, if any, in the store's storage 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.

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.



◄ **FIGURE 16.8 Diagram of Outbound Stockpoint with Warning-Signal Marker**

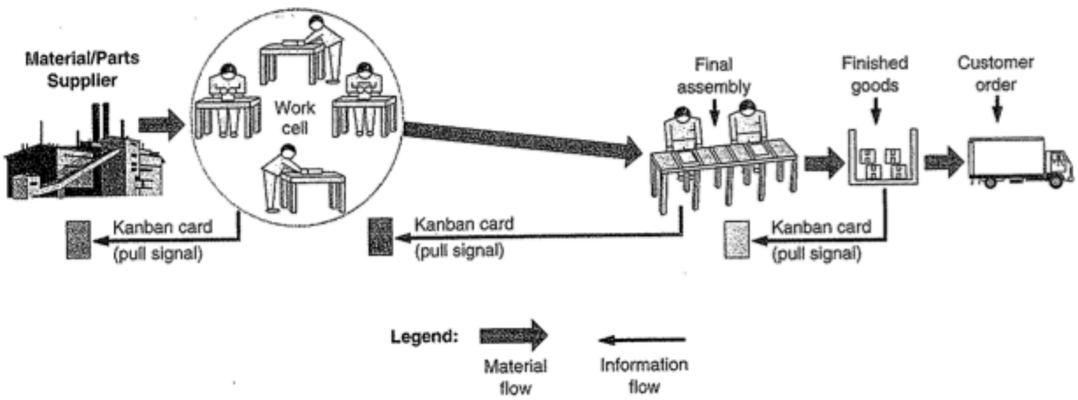
Several additional points regarding kanbans may be helpful:

- When the producer and user are not in visual contact, a card can be used; otherwise, a light or flag or empty spot on the floor may be adequate.
- Because a pull station may require several resupply components, several kanban pull techniques can be used for different products at the same pull station.
- Usually, each card controls a specific quantity of parts, although multiple card systems are used if the producing work cell produces several components or if the lot size is different from the move size.
- In an MRP system (see Chapter 14), the schedule can be thought of as a "build" authorization and the kanban as a type of "pull" system that initiates the actual production.
- The kanban cards provide a direct control (limit) on the amount of work-in-process between cells.
- If there is an immediate storage area, a two-card system may be used—one card circulates between user and storage area, and the other circulates between the storage area and the producing area.

Determining the Number of Kanban Cards or Containers The number of kanban cards, or containers, in a JIT system 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

▼ **FIGURE 16.9 Kanban Signals "Pull" Material Through the Production Process**

As a customer "pulls" an order from finished goods, a signal (kanban card) is sent to the final assembly area. Final assembly produces and resupplies finished goods. When final assembly needs components, it sends a signal to *its* supplier, a work cell. The work cell, in turn, sends a signal to the material/parts supplier.



model such as the production order quantity model (discussed in Chapter 12 and shown again on page 661 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:

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

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.

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

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

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

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

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

SOLUTION ▶ Demand during lead time =

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

$$\text{Safety stock} = 250$$

LO6: Compute the required number of kanbans

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 ▶ 16.1, 16.2, 16.3, 16.4, 16.5, 16.6

Advantages of Kanban Containers are typically very small, usually a matter of a few hours' worth of production. Such a system requires tight schedules. Small quantities must be produced several times a day. The process must run smoothly with little variability in quality of 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.

Whether it is called kanban or something else, the advantages of small inventory and *pulling* material through the plant only when needed are significant. For instance, small batches allow only a very limited amount of faulty or delayed material. Problems are immediately evident. Numerous aspects of inventory are bad; only one aspect—availability—is good. Among the bad aspects are poor quality, obsolescence, damage, occupied space, committed assets, increased insurance, increased material handling, and increased accidents. Kanban systems put downward pressure on all these negative aspects of inventory.

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 in trailers, and require less labor to pack, unpack, and prepare items.

AUTHOR COMMENT Good quality costs less.

JIT QUALITY

The relationship between JIT and quality is a strong one. They are related in three ways. First, JIT cuts the cost of obtaining good quality. This saving occurs because scrap, rework, inventory investment, and damage costs are buried in inventory. JIT forces down inventory; therefore, fewer bad units are produced and fewer units must be reworked. In short, whereas inventory *hides* bad quality, JIT immediately *exposes* it.

This auto plant, like most JIT facilities, empowers employees so they can stop the entire production line by pulling the overhead cord if any quality problems are spotted.

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

Finally, better quality means fewer buffers are needed and, therefore, a better, easier-to-employ JIT system can exist. Often the purpose of keeping inventory is to protect against unreliable quality. If consistent quality exists, JIT allows firms to reduce all costs associated with inventory. Table 16.4 suggests some requirements for quality in a JIT environment.

▼ **TABLE 16.4**
JIT Quality Tactics

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

TOYOTA PRODUCTION SYSTEM

AUTHOR COMMENT
TPS brings the entire person to work.

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 core components of TPS are continuous improvement, respect for people, and standard work practice.

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.* In application, it means making a multitude of small or incremental changes as one seeks ellusive perfection. (See the *OM in Action Box* "Kaizen at Novo Nordisk."). Instilling the mantra of continuous improvement begins at 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.

Respect for People

At Toyota, people are recruited, trained, and treated as knowledge workers. Aided by aggressive cross-training and few job classifications, TPS engages the mental as well as physical capacities of employees in the challenging task of improving operations. Employees are empowered. They are empowered to make improvements. They are empowered to stop machines and processes when quality problems exist. Indeed, empowered employees are a necessary part of TPS. 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. TPS respects employees by giving them the opportunity to enrich both their jobs and their lives.

Standard Work Practice

Standard work practice at Toyota includes these underlying principles:

LO7: Explain the principles of the Toyota Production System

- Work is completely specified as to content, sequence, timing, and outcome.
- Internal and external customer–supplier connections are direct, specifying personnel, methods, timing, and quantity.

OM in Action ▶ Kaizen at Novo Nordisk

Novo Nordisk is a health care company and a world leader in diabetes care. With headquarters in Denmark, Novo Nordisk employs more than 29,000 employees in 81 countries, and its markets its products in 179 countries.

The remarkable annual result in 2009 of $9.1 billion was due to a thorough optimization process, especially due to the reengineering of its production processes by using a lean operation called cLEAN. cLEAN allows the same number of workers to produce twice as much of its insulin and growth hormones.

One way Novo Nordisk achieved these results was through kaizen, in which each of the 9,000 employees asks themselves daily whether it would be possible to perform in a smarter way. One employee suggested replacing air-powered cylinders in an engine with server engines, so that the movements could be more; these changes allowed assembly with greater precision, with less waste and fewer errors. This single suggestion has saved around $143,000 per year at full production.

Everybody at Novo Nordisk is able to see how productivity can be increased and waste can be decreased by applying cLEAN. Every department is expected to hand in a couple ideas every year so that the number of suggestions that lead immediately to significant economic improvements will continue to increase.

cLEAN has positively affected logistics and supply-chain operations at Novo Nordisk, as shown by its 99.9% delivery reliability and quality.

Sources: Mette Buck Jensen, (2009) "Novo fandt gevinsten i de små ting," Ingeniøren, October 2009, 8–14, and **www.novonordisk.com**.

- Product and service flows are to be simple and direct. Goods and services are directed to a specific person or machine.
- Improvements in the system must be made in accordance with the "scientific method," at the lowest possible level in the organization.[2]

TPS requires that activities, connections, and flows include built-in tests to automatically signal problems. Any gap between what is expected and what occurs becomes immediately evident. The education and training of Toyota's employees and the responsiveness of the system to problems make the seemingly rigid system flexible and adaptable to changing circumstances. The result is ongoing improvements in reliability, flexibility, safety, and efficiency.

AUTHOR COMMENT Lean drives out non-value-added activities.

LEAN OPERATIONS

Lean production can be thought of as the end result of a well-run OM function. While JIT and TPS tend to have an *internal* focus, lean production begins *externally* with a focus on the customer. Understanding what the customer wants and ensuring customer input and feedback are starting points for lean production. Lean operations means identifying customer value by analyzing all the activities required to produce the product and then optimizing the entire process from the customer's perspective.

Building a Lean Organization

The transition to lean production is difficult. Building an organizational culture where learning, empowerment, and continuous improvement are the norm is a challenge. However, organizations that focus on JIT, quality, and employee empowerment are often lean producers. Such firms drive out activities that do not add value in the eyes of the customer: they include leaders like United Parcel Service, Harley-Davidson, and, of course, Toyota. Even traditionally craft-oriented organizations such as Louis Vuitton (see the *OM in Action* box) 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:

- *Use JIT techniques* to eliminate virtually all inventory.
- *Build systems that help employees* produce a perfect part every time.
- *Reduce space requirements* by minimizing travel distance.

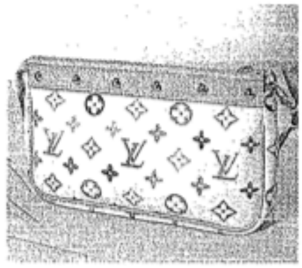
[2]Adopted from Steven J. Spear, "Learning to Lead at Toyota," *Harvard Business Review* 82, no. 5 (May 2004): 78–86; and Steven Spear and H. Kent Bowen, "Decoding the DNA of the Toyota Production System," *Harvard Business Review* 77, no. 5 (September–October 1999): 97–106.

OM in Action ▶ Going Lean at Louis Vuitton

LVMH Moet Hennessy Louis Vuitton is the world's largest luxury-goods company. Its Louis Vuitton unit, responsible for half of the company's profit, makes very upscale handbags and enjoys a rich markup on sales of about $5 billion. The return-on-investment is excellent, but sales could be even better: the firm often can't match production to the sales pace of a successful new product. In the high fashion business that is all about speed-to-market, this is bad news; a massive overhaul was in order.

Changes on the factory floor were key to the overhaul. The traditional approach to manufacturing at Louis Vuitton was batch production: craftsmen, working on partially completed handbags, performed specialized tasks such as cutting, gluing, sewing, and assembly. Carts moved batches of semi-finished handbags on to the next workstation. It took 20 to 30 workers 8 days to make a handbag. And defects were high. Lean manufacturing looked like the way to go.

Craftsmen were retrained to do multiple tasks in small U-shaped work cells. Each work cell now contains 6 to 12 cross-trained workers and the necessary sewing machines and work tables. Consistent with one-piece flow, the work is passed through the cell from worker to worker. The system reduces inventory and allows workers to detect flaws earlier. Rework under the old system was sometimes as high as 50% and internal losses as high as 4%. Returns are down by two-thirds. The system has not only improved productivity and quality, it also allows Louis Vuitton to respond to the market faster—with daily scheduling as opposed to weekly scheduling.



Sources: The Wall Street Journal (October 9, 2006): A1, A15 and (January 31, 2006): A1, A13.

- *Develop partnerships with suppliers*, helping them to understand the needs of the ultimate customer.
- *Educate suppliers* to accept responsibility for satisfying end customer needs.
- *Eliminate all but value-added activities.* Material handling, inspection, inventory, and rework are the likely targets because these do not add value to the product.
- *Develop employees* by constantly improving job design, training, employee commitment, teamwork, and empowerment.
- *Make jobs challenging*, pushing responsibility to the lowest level possible.
- *Build worker flexibility* through cross-training and reducing job classifications.

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

LEAN OPERATIONS IN SERVICES

AUTHOR COMMENT
JIT, TPS, and lean began in factories but are now also used in services throughout the world.

The features of lean operations apply to services just as they do in other sectors. (See the *OM in Action* box "Toyota University Teaches Lean Thinking.") Here are some examples applied to suppliers, layout, inventory, and scheduling in the service sector.

Suppliers As we have noted, 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 or get sick.

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 in airline baggage claim, where customers expect their bags just-in-time.

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 finished-goods inventory of only 10 minutes; after that, it is thrown away. Hospitals, such as Arnold Palmer (described in this chapter's

VIDEO 16.1
JIT at Arnold Palmer Hospital

Lean operations take on an unusual form in an operating room. McKesson-General, Baxter International, and many other hospital suppliers provide surgical supplies for hospitals on a JIT basis. (1) They deliver prepackaged surgical supplies based on hospital operating schedules, and (2) the surgical packages themselves are prepared so supplies are available in the sequence in which they will be used during surgery.

Video Case Study), manage JIT inventory and low safety stocks for many items. Even critical supplies such as pharmaceuticals may be held to low levels by developing community networks as backup systems. 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.

Scheduling At airline ticket counters, the focus of the system is on adjusting to customer demand. But rather than being accommodated by inventory availability, demand is satisfied by personnel. Through elaborate scheduling, ticket counter personnel show up just-in-time to cover peaks in customer demand. In other words, rather than "things" inventoried, personnel are scheduled. At a salon, the focus is only slightly different: the *customer* and the staff are scheduled to assure prompt service. At McDonald's and Walmart, scheduling of personnel is down to 15-minute increments, based on precise forecasting of demand. Additionally, at McDonald's, production is done in small lots to ensure that fresh, hot hamburgers are delivered just-in-time. In short, both personnel and production are scheduled to meet specific demand. Notice that in all three of these lean organizations—the airline ticket counter, the salon, and McDonald's—scheduling is a key ingredient. Excellent forecasts drive those schedules. Those 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 lean, cycle times short, and schedules nimble. A lean focus engages and empowers employees to create and deliver the customer's perception of value, eliminating whatever does not contribute to this goal. Lean operations are currently being developed with great success in many firms, regardless of their products. Lean techniques are widely used in both goods-producing and service-producing firms; they just look different.

OM in Action ▶ Toyota University Teaches Lean Thinking

Based in Gardenia, California, Toyota University teaches its employees the Toyota Production System. But Toyota has also opened its door to others. As a public service, Toyota has been teaching lean thinking classes to the Los Angeles Police Department and the U.S. military. Classes begin, as one might expect, with a car-building exercise. Using model cars and desks as workstations and delivery areas, students begin with a focus on fast throughput and high production goals. This results in a "push" system, with lots of work-in-process piling up, lots of defects to be reworked, and too many of the wrong kind of cars on the "dealer's" lot.

The exercise is then revised, and students are taught to respond to orders and to form *kaizen* (continuous improvement) teams. The revised exercise then uses a "pull" system that responds to orders and fixes even the most minor problems immediately. With a focus only on filling orders and "pulling" demand through the production process with no defects, a faster, more efficient production line is formed.

Instructor Matthew May's observation about adapting lean methods beyond the factory: "If you can do it with LAPD, you can do it anywhere."

Sources: The Wall Street Journal (March 5, 2007): B1, B4; and **www.isosupport.com**.

CHAPTER SUMMARY

JIT, TPS, and lean operations are philosophies of continuous improvement. Lean operations focus on customer desires, TPS focuses on respect for people and standard work practices, and JIT focuses on driving out waste by reducing inventory. But all three approaches reduce waste in the production process. And 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 these systems is that empowered employees work with committed management to build systems that respond to customers with ever-lower cost and higher quality.

Key Terms

Just-in-time (JIT) (p. 654)
Toyota Production System (TPS) (p. 654)
Lean operations (p. 654)
Seven wastes (p. 654)
5Ss (p. 655)
Variability (p. 655)
Throughput (p. 656)
Manufacturing cycle time (p. 656)
Pull system (p. 656)
JIT partnerships (p. 657)
Consignment inventory (p. 657)
Just-in-time inventory (p. 660)
Level schedules (p. 663)
Kanban (p. 664)
Kaizen (p. 667)

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 correct truck and store and 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 them, you are probably out of business. What are the ethical issues and what do you do?

Discussion Questions

1. What is JIT?
2. What is a lean producer?
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 JIT and quality are related?
7. How does TPS contribute to competitive advantage?
8. What are the characteristics of just-in-time 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 fairly 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 illustration.
12. Which lean techniques work in both the manufacturing *and* service sectors?

Solved Problems

Virtual Office Hours help is available at www.pearsonglobaleditions.com/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:

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

$= \sqrt{10{,}000} = 100$ 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*

• **16.1** Leblanc Electronics, Inc., in Nashville, produces short runs of custom airwave scanners for the defense industry. You have been asked by the owner, Larry Leblanc, 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

• **16.2** Chip Gillikin'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
Production lead time	$\frac{1}{2}$ day
Safety stock	$\frac{1}{4}$ day
Kanban size	50 units

•• **16.3** Chris Millikan 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

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

•• **16.4** 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 PX

• **16.5** 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, 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? PX

••• **16.6** Discount-Mart (see Problem 16.5), as part of its new JIT 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? PX

•• **16.7** How do your answers to Problems 16.5 and 16.6 provide insight into a JIT purchasing strategy?

••• **16.8** Bill Penny has a repetitive manufacturing plant producing trailer hitches in Arlington, Texas. The plant has an average inventory turnover of only 12 times per year. He has therefore determined that he will reduce his component lot sizes. He 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 he have his plant manager aim for regarding this component?

••• **16.9** Given the following information about a product, at Phyllis Simon'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

••• **16.10** 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?

▶ **Refer to myomlab for these additional homework problems: 16.11–16.12**

Case Studies

▶ Mutual Insurance Company of Iowa

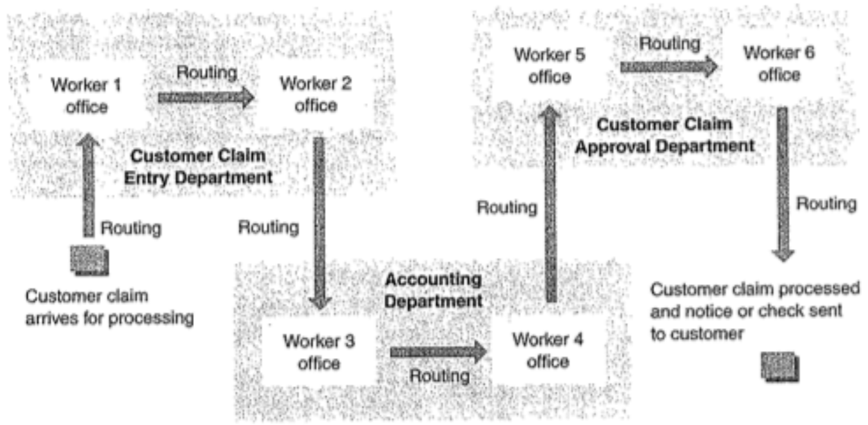
Mutual Insurance Company of Iowa (MICI) has a major insurance office facility located in Des Moines, Iowa. The Des Moines office is responsible for processing all of MICI's insurance claims for the entire nation. The company's sales have experienced rapid growth during the last year, and as expected, record levels in claims followed. Over 2,500 forms for claims a day are now flowing into the office for processing. Unfortunately, fewer than 2,500 forms a day are flowing out. The total time to process a claim, from the time it arrives to the time a check is mailed, has increased from 10 days to 10 weeks. As a result, some customers are threatening legal action. Sally Cook, the manager of Claims Processing, is particularly distressed, as she knows that a claim seldom requires more than 3 hours of actual work. Under the current administrative procedures, human resources limitations, and facility constraints, there appear to be no easy fixes for the problem. But clearly, something must be done, as the workload has overwhelmed the existing system.

MICI management wants aggressive, but economical, action taken to fix the problem. Ms. Cook has decided to try a JIT approach to claim processing. With support from her bosses, and as a temporary fix, Cook has brought in part-time personnel from MICI sales divisions across the country to help. They are to work down the claims backlog while a new JIT system is installed.

Meanwhile, Claims Processing managers and employees are to be trained in JIT principles. With JIT principles firmly in mind, managers will redesign jobs to move responsibilities for quality control activities to each employee, holding them responsible for quality work and any necessary corrections. Cook will also initiate worker-training programs that explain the entire claim processing flow, as well as provide comprehensive training on each step in the process. Data-entry skills will also be taught to both employees and managers in an effort to fix responsibility for data accuracy on the processor rather than on data entry clerks. Additionally, cross-training will be emphasized to enable workers within departments to process a variety of customer claim applications in their entirety.

Cook and her supervisors are also reexamining the insurance and claim forms currently in use. They want to see if standardization of forms will cut processing time, reduce data-entry time, and cut work-in-process.

They hope the changes will also save training time. Making changes in work methods and worker skills leads logically to a need for change in the layout of the Claims Processing Department. This potential change represents a major move from the departmental layout of the past, and will be a costly step. To help ensure the successful implementation of this phase of the



▲ FIGURE 16.10 **Claims Processing Department Layout**

changeover, Cook established a team made up of supervisors, employees, and an outside office layout consultant. She also had the team visit the Kawasaki motorcycle plant in Lincoln, Nebraska, to observe their use of work cells to aid JIT.

The team concluded that a change in the office facilities was necessary to successfully implement and integrate JIT concepts at MICI. The team believes it should revise the layout of the operation and work methods to bring them in line with "group technology cell" layouts. An example of the current departmental layout and claim processing flow pattern is presented in Figure 16.10. As can be seen in this figure, customer claims arrive for processing at the facility and flow through a series of offices and departments to eventually complete the claim process. Although the arrangement of the offices and workers in Figure 16.10 is typical, the entire facility actually operates 20 additional flows, each consisting of the same three departments. However, not all of the 20 flows are configured the same. The number of employees, for example, varies depending on the claim form requirements (larger claims have to be approved by more people). So while all forms must pass through the same three departments (Customer Claim Entry, Accounting, and Customer Claim Approval), the number of workers for each claim may vary from two to four. For this reason, the MICI facility currently maintains a staff of over 180 office workers just to process and route claims. All these people work for Ms. Cook.

Discussion Questions

1. Identify the attributes you would expect the Claims Processing Department at MICI to have once the new JIT system is in place.
2. What will the restructured cell layout for claim processing in Figure 16.10 look like? Draw it.
3. What assumptions are you making about personnel and equipment in the new group technology cell layout?
4. How will the new JIT oriented system benefit the MICI operation? Explain.

Source: Adapted from Marc J. Schniederjans, *Topics in Just-in-Time Management*, pp. 283–285. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.

▶ JIT after a Catastrophe

You name the catastrophe, and JIT has been through it and survived. Toyota Motor Corporation has had its world-renowned JIT system tested by fire. The massive fire incinerated the main source of crucial brake valves that Toyota buys from the Aisin Seiki plant in Kariya, Japan, and uses in most of its cars. The impact was the loss of 70,000 cars not produced while Toyota got the supply chain repaired. Then an earthquake destroyed Toyota's transmission supplier, Riken, shutting down production in a dozen factories. Chrysler and many others had their JIT systems tested on September 11, 2001, when the terrorists attacks shut down their state-of-the-art air delivery systems. And on February 5, 2008, during the second shift at Caterpillar's high-pressure couplings plant in Oxford, Mississippi, a tornado all but destroyed the facility. Despite these catastrophes, managers at these firms, like other executives all over the world, are still cutting costs by consolidating production, reducing inventory, and implementing JIT.

Consistent with JIT practice, these firms maintain minimal inventory of components and tight supply chains. There are very few components in these closely knit networks that constitute their respective supply chains. Without critical components, production comes to a rapid halt. And in Caterpillar's case, the Oxford plant is the only plant in the world that makes this unique coupling. The couplings link hydraulic hoses on *every* piece of machinery Caterpillar makes. Depending on a single source and holding little inventory is a risk, but it also keeps firms lean and costs low.

The morning after the tornado tore apart the Oxford plant, Greg Folley, who runs Caterpillar's parts division, toured the plant. Much of the roof, including 10-ton heating and air-conditioning units, had fallen onto three critical metal stamping machines. The first piece of equipment was up and running in 2 weeks; getting production back to normal would take 6 months. But the Oxford plant had been making over 1 million of the critical couplings each month; this left a huge hole in Caterpillar's supply line.

Discussion Questions

1. If you are Mr. Folley, looking over the devastation at the Oxford plant, what do you do to keep Caterpillar's worldwide production running?
2. Given the inherent risk in JIT and the trauma that the companies have experienced, why has JIT survived?
3. What do these experiences, and the continuing popularity of JIT, tell you about just-in-time?
4. What actions or changes in policy do you suggest for Caterpillar?

Sources: Case is based on material in: *The Wall Street Journal* (May 19, 2008): B1, B2; (July 20, 2007): B1; **www.USAToday.com/money/world/2007-07-18-toyota-quake**; and *Harvard Business Review* (September–October 1999): 97–106.

▶ 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 16,000 births per year, and growing), 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 nursing workstations via dispensing machines (almost like vending machines) that electronically track patient usage and post the related charge to each patient. The dispensing stations are refilled each night, based on patient demand and prescriptions written by doctors.

To address JIT issues externally, Arnold Palmer Hospital turned toward 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, expensive, and must remain sterile. Reducing the inventory and handling while maintaining an assured 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.

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Chapter 16 Rapid Review

Main Heading	Review Material	
JUST-IN-TIME, THE TOYOTA PRODUCTION SYSTEM, AND LEAN OPERATIONS (pp. 654–656)	■ **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. ■ **Lean operations**—Eliminates waste through a focus on exactly what the customer wants. *When implemented as a comprehensive manufacturing strategy, JIT, TPS, and lean 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 time required to move orders through the production process, from receipt to delivery. ■ **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.	
JUST-IN-TIME (JIT) (pp. 656–659)	■ **JIT partnerships**—Partnerships of suppliers and purchasers that remove waste and drive down costs for mutual benefits. Some specific goals of JIT 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 JIT partnerships include: (1) *diversification*; (2) *scheduling*; (3) *lead time*; (4) *quality*; and (5) *lot sizes*.	
JIT LAYOUT (pp. 659–660)	JIT layout tactics include building work cells for families of products, include 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.	
JIT INVENTORY (pp. 660–662)	■ **Just-in-time 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. JIT 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. $$Q^* = \sqrt{\frac{2DS}{H[1-(d/p)]}} \quad (16\text{-}1)$$ Using (16–1), for a given desired lot size, Q, we can solve for the optimal setup cost, S: $$S = \frac{(Q^2)(H)(1-d/p)}{2D} \quad (16\text{-}2)$$	Problems: 16.8–16.10

Chapter 16 **Rapid Review** *continued*

Main Heading	Review Material	myomlab
JIT SCHEDULING (pp. 662–666)	JIT 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: $\text{Number of Kanbans (containers)} = \dfrac{\text{Demand during lead time} + \text{Safety stock}}{\text{Size of container}}$ (16-3)	Problems: 16.1–16.6 Virtual Office Hours for Solved Problem: 16.1
JIT QUALITY (pp. 666–667)	Whereas inventory *hides* bad quality, JIT immediately *exposes* it. JIT quality tactics include using statistical process control, empowering employees, building fail-safe methods (poka-yoke, checklists, etc.), exposing poor quality with small lot JIT, and providing immediate feedback.	
TOYOTA PRODUCTION SYSTEM (pp. 667–668)	■ **Kaizen**—A focus on continuous improvement. At Toyota, people are recruited, trained, and treated as knowledge workers. They are empowered. TPS employs aggressive cross-training and few job classifications.	
LEAN OPERATIONS (pp. 668–669)	Lean operations tend to share the following attributes: *use JIT techniques* to eliminate virtually all inventory; *build systems that help employees* produce a perfect part every time; *reduce space requirements* by minimizing travel distance; *develop partnerships with suppliers*, helping them to understand the needs of the ultimate customer; *educate suppliers* to accept responsibility for satisfying end customer needs; *eliminate all but value-added activities*; *develop employees* by constantly improving job design, training, employee commitment, teamwork, and empowerment; *make jobs challenging*, pushing responsibility to the lowest level possible; and *build worker flexibility* through cross-training and reducing job classifications.	
LEAN OPERATIONS IN SERVICES (pp. 669–670)	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.	**VIDEO 16.1** 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.

LO1. Continuous improvement and forced problem solving via a focus on throughput and reduced inventory is a reasonable definition of:
- **a)** lean operations.
- **b)** expedited management.
- **c)** the 5Ss of housekeeping.
- **d)** just-in-time.
- **e)** Toyota Production System.

LO2. The 5Ss for lean production are ______, ______, ______, ______, and ______.

LO3. Concerns of suppliers when moving to JIT 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.

LO4. 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)** $H(1 - d/p)$

LO5. Kanban is the Japanese word for:
- **a)** car.
- **b)** pull.
- **c)** card.
- **d)** continuous improvement.
- **e)** level schedule.

LO6. 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.

LO7. TPS's standard work practices include:
- **a)** completely specified work.
- **b)** "pull" systems.
- **c)** level scheduling.
- **d)** kanbans.
- **e)** JIT techniques.

Answers: LO1. d; LO2. sort, simplify, shine, standardize, sustain; LO3. e; LO4. d; LO5. c; LO6. e; LO7. a.