CHAPTER 6

PROCESS ANALYSIS

Learning Objectives:

1. Understand process analysis.
2. Know how to prepare a process flowchart.
3. Understand the different types of processes used by businesses.
4. Calculate the different measures of process performance.

FASTER SERVICE HAS BENEFITS AND COSTS

Saying "HimayItakeyourorderplease?" takes only one second for the drive-through greeter at Wendy's Old-Fashioned Hamburgers. This is two seconds faster than Wendy's guidelines and illustrates the effort fast food chains are putting into speeding up their drive-through pick-up windows. Cars spent on average 150.3 seconds at Wendy's, the leader in this category, which made it 16.7 seconds and 21 seconds faster than McDonald's and Burger King respectively. Yet, far from resting on its laurels, Wendy's is working hard to reduce this time even further.

Why this emphasis on reducing process and waiting times? The drive-through business has been growing at a faster rate than on-premise sales. Since the growth in the number of new restaurants is slowing, the big chains are focusing on this newer battleground, drive-through sales. Using product development, employee retraining, and new technology, McDonald's, Burger King, Arby's, Taco Bell, and others are battling to be the fastest in the business. It is estimated that increasing drive-through efficiency by 10 percent bolsters sales for the average fast-food restaurant by about 10 percent per year.

Wendy's and Burger King are building special drive-through kitchens, while McDonald's is experimenting with windshield transponders that can automatically bill the purchaser's account, making the cash transaction redundant. McDonald's estimates that it can shave off 15 seconds from its drive-through time and boost sales by 2 percent. Timers, kitchen choreography designed to eliminate unnecessary movement, and wireless headsets that let all workers hear customer orders, are other initiatives. Sounding alarms such as beeps, sirens, and even voices congratulating or admonishing crews are also being used. Tim Horton's recently stopped making donuts at is locations and outsourced them to Maidstone Bakeries of Brantford, Ontario. Maidstone ships frozen donuts to Tim Horton's locations in Canada and the U.S. This allows the Tim Horton's stores to make donuts quickly by reheating them.

Is there a trade-off in speeding up the service? The same survey that placed Wendy's on top in speed also ranked it eleventh in accuracy. University student Clint Toland and his girlfriend recently drove through a Taco Bell to get a late-night meal of nachos with meat but no beans, only to discover back at home that the order contained beans and no meat. Says he, "I am never coming back."

Speed can also be stressful for employees. After nine months at a drive-through, night manager Tiffany Swan Holloway vows never to work again in fast food. Her small night crew had a hard time keeping up with the 60-second service goal, and the beepers irritated her too. In the case of Tim Hortons, some may argue that freezing donuts and reheating them later could reduce their taste quality (though others might argue that making fresh donuts in the store in large batches can result in donuts becoming stale a few hours later).

This is a good illustration of some of the trade-offs in process design. Although faster processes are desirable, ultimately they may not be desirable at the cost of lower quality or higher server stress.

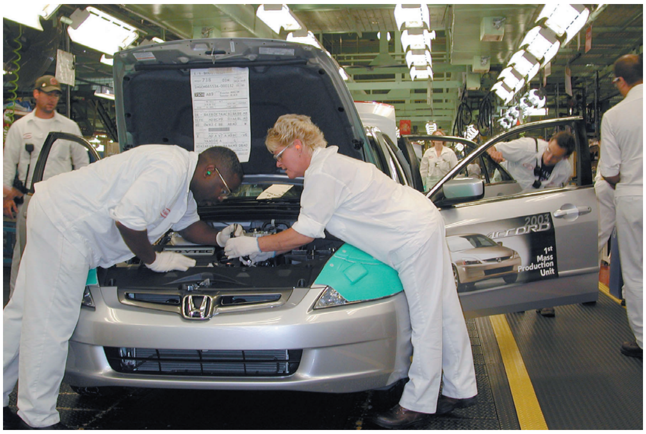
■ Sources: http://en.wikipedia.org/wiki/Tim_Hortons, retrieved, February 7, 2009.
http://www.brantfordbrant.com/publications/E.D.NewsletterSummer.07.pdf, retrieved, February 7, 2009.
Jennifer Ordonez, "Next! An Efficiency Drive: Fast-Food Lanes Are Getting Even Faster—Big Chains, Vying for Traffic, Use High-Tech Timers, 'Kitchen Choreography'—Mesclun in a Milkshake Cup?" *Wall Street Journal*, May 18, 2000, A1.

PROCESS ANALYSIS

What is a process? A **process** is any part of an organization that takes inputs and transforms them into outputs that, it is hoped, are of greater value to the organization than the original inputs. Consider some examples of processes. Honda Motors assembles the Civic in a plant in Alliston, Ontario. The assembly plant takes in parts and components that have been fabricated for the plant. Using labour, equipment along an assembly line, and energy, these parts and components are transformed into automobiles. McDonald's, at each of its restaurants, uses inputs such as hamburger meat, lettuce, tomatoes, and potatoes. To these inputs, trained labour is added in the form of cooks and order takers, and capital equipment is used to transform the inputs into hamburgers, french fries, and other foods.

In both of these examples, the process produces products as output. However, the outputs of many processes are services. In a hospital, for example, specialized equipment and highly trained doctors, nurses, and technicians are combined with another input, the patient. The patient is transformed through proper treatment and care into a healthy patient. An airline is another example of a service organization. The airline uses airplanes, ground equipment, flight crews, ground crews, reservation personnel, and fuel to transport customers and freight between locations all over the world.

This chapter describes how to analyze a process. Analyzing a process allows some important questions to be answered, such as these: How many customers can the process



A stage in the assembly line process of producing an automobile where inputs are transformed into outputs. The line is paced as the car moves from one stage to the next after a fixed time interval.

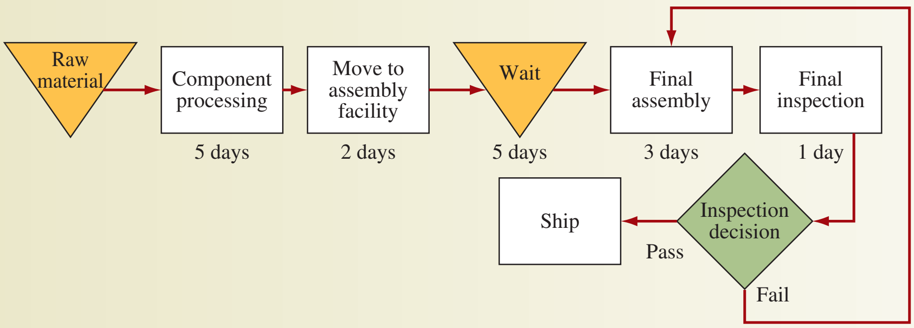
handle per hour? How long will it take to serve a customer? What change is needed in the process to expand capacity? How much does the process cost? A difficult, but important, first step in process analysis is to clearly define the purpose of the analysis. Is the purpose to solve a problem? Is it to better understand the impact of a change in how business will be done in the future?

Clearly understanding the purpose of the analysis is critical to setting the level of detail in modelling the process. Keep the analysis as simple as possible. The following sections of this chapter discuss the details of constructing flowcharts and measures that are appropriate for different types of processes. But first, consider a simple example.

PROCESS FLOWCHARTING

Often, the activities associated with a process affect one another, so it is important to consider the simultaneous performance of a number of activities, all operating at the same time. A good way to start analyzing a process is with a diagram showing the basic elements of a process—typically, tasks, flows, and storage areas. Tasks are shown as rectangles, flows as arrows, and the storage of goods or other items as inverted triangles. Sometimes, flows through a process can be diverted in multiple directions depending on some condition. Decision points are depicted as a diamond, with the different flows running from the points on the diamond. Exhibit 6.1 displays examples of these symbols, along with their use in an example.

EXHIBIT 6.1



The example shown is that of a product that is made from processed components. The raw material for processing is held in inventory. When the product is ready to be manufactured, the raw material is withdrawn from the inventory in appropriate quantities and the components are made. Then these components are shipped to the second facility where they wait for some time before being assembled into the final product. The product then goes through a final inspection. If it passes inspection it is shipped. Otherwise, it is returned to the final assembly area for rework. The flowchart could be more or less detailed, as required. For example, Exhibit 6.1 does not include the option for inspection after component processing. This could be added if appropriate. Further, the component processing and final assembly process nodes could be expanded to show more detail. One important advantage of process flowcharting is that it allows decision makers to identify opportunities for improving the process. For example, one may question why components need to be moved to a second facility for assembly, thus encountering delays. This might lead to reorganization of the process so that all the processing is done in one facility, resulting in a faster process. Thus, process flowcharting is related to a concept called Value Stream Mapping (VSM) which analyzses processes for improvement.

An easy way to draw flowcharts is to use the Shapes gallery available in the Microsoft Office programs (i.e., Word, Excel, and PowerPoint). For more sophisticated flow charting, other, more dedicated, flowcharting software is also available.

Cycle Time and Utilization

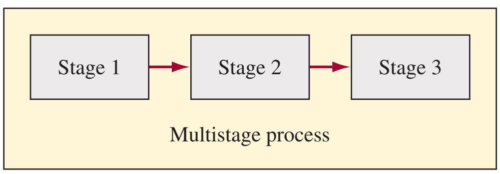
The cycle time (discussed in Chapter 5) of a repetitive process is the average time between completions of successive units. Suppose we have an automatic car wash that can wash one car in 3 minutes. Assuming that there are many cars waiting to be washed all the time, the cycle time for the wash is then 3 minutes, i.e., a car comes out of the wash every 3 minutes. However, if, on average, only 10 cars come in an hour, then the actual cycle time is 6 minutes (one car coming out every 6 minutes on average), even though the fastest cycle time for the car wash is 3 minutes. To be consistent, in this text the term "cycle time" refers to the fastest cycle time

Note that this car wash can handle 20 cars an hour (3 minutes per car). If, in reality, only 10 cars on average arrive in an hour, the utilization of this facility is only 50 percent (10 cars per hour/20 cars per hour). Utilization is the ratio of the time that a resource is actually activated relative to the time that it is available for use (also see Chapter 4).

TYPES OF PROCESSES

It is useful to categorize processes to describe how a process is designed. By being able to quickly categorize a process, we can show the similarities and differences between processes. We will also see that the type of process used should tie in with the position of the product on the product–process matrix discussed in Chapter 5.

The first way to categorize a process is to determine whether it is a *single-stage* or a *multiple-stage* process. If the process in Exhibit 6.1 were viewed as a simple black box, it would be categorized as a single-stage process. In this case, all of the activities in the process would be collapsed and analyzed using a single cycle time to represent its speed. A multiple-stage process has multiple groups of activities that are linked through flows. The term *stage* is used to indicate that multiple activities have been pulled together for analysis purposes.



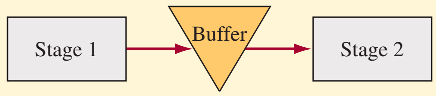
Buffering, Blocking, and Starving

A multiple-stage process may be buffered internally. **Buffering** refers to a storage area between stages where the output of a stage is placed prior to being used in a downstream stage. Buffering allows the stages to operate independently. If one stage feeds a second stage with no intermediate buffer, then the assumption is that the two stages are directly linked. When a process is designed this way, the most common problems that can happen are blocking and starving. **Blocking** occurs when the activities in the stage must stop because there is no place to deposit the item just completed. **Starving** occurs when the activities in a stage must stop because there is no work.

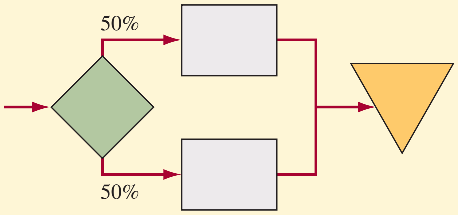
Consider a two-stage process where the first stage has a cycle time of 30 seconds and the second a cycle time of 45 seconds. If this process needs to produce 100 units, then the first stage would be blocked for 15 seconds for each unit produced.

What would happen if an inventory buffer were placed between the two stages? In this case, the first stage would complete the 100 units in 3000 seconds (30 seconds/unit × 100 units). During these 3000 seconds, the second stage would complete only 66 units ((3000 − 30) seconds/45 seconds/unit). The 30 seconds are subtracted from the 3000 seconds because the second stage is starved for the first 30 seconds. This would mean that the inventory would build up to 34 units (100 units − 66 units) over that first 3000 seconds. All of the units would be produced in 4530 seconds. The second stage in this case is called a **bottleneck** because it limits the capacity of the process.

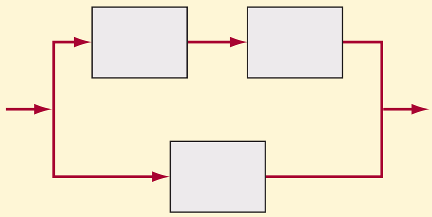
What would happen if the first stage required 45 seconds and the second stage had the 30-second cycle time? In this case, the first stage would be the bottleneck, and each unit would go directly from the first stage to the second. The second stage would be starved for 15 seconds waiting for each unit to arrive; however, it would still take 4530 seconds to complete all 100 units. Note that the cycle time is 45 seconds (one unit comes out every 45 seconds) which is the time required to process each unit at the bottleneck stage. So the cycle time is related to the processing time at the bottleneck. All of this assumes that there is no variability in the cycle time. With the relatively low 67 percent utilization on the second stage, variability would have little impact on the performance of this system, but if the cycle times were closer, some inventory might collect in the buffer.



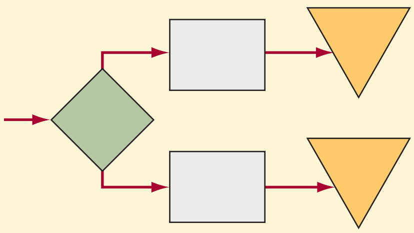
Multistage process with buffer



Alternative paths



Simultaneous activities



Different products produced

Often, activities, stages, and even entire processes are operated in parallel. For example, operating two identical activities in parallel would theoretically double capacity. Or perhaps two different sets of activities can be done at the same time on the unit being produced. In analyzing a system with parallel activities or stages, it is important to understand the context. In the case where parallel processes represent alternatives, for example, a diamond should show that flows divert and what percentage of the flow moves in each direction. Sometimes, two or more processes terminate in a common inventory buffer. Normally, this indicates that the two processes make identical items that are going into this inventory. Separate inventories should be used in the diagram if the outputs of the parallel processes are different.

Make-to-Stock versus Make-to-Order

Another useful way to characterize a process is whether the process *makes to stock* or *makes to order*. To illustrate these concepts, consider the processes used to make hamburgers at the three major fast-food restaurant chains in North America: McDonald's, Burger King, and Wendy's. In the case of McDonald's, in 1999 the company converted to a new make-to-order process, but the company has now revised that into a "hybrid" system. We begin our tour of the approaches used by the top fast-food restaurants by first reviewing the traditional approach.

Consider a traditional restaurant making hamburgers. Before the era of fast food, hamburgers were always made to order. In the traditional process, the customer places an order specifying the degree of cooking (medium or well done) and requests specific condiments (pickles, cheese, mustard, onions, ketchup). Using this specification, the cook takes raw hamburger meat from inventory (typically, this inventory is refrigerated and the patties have already been made), cooks the hamburger, and warms the bun. The hamburger is then assembled and delivered to the customer. The quality of the hamburger is highly dependent on the skill of the cook.

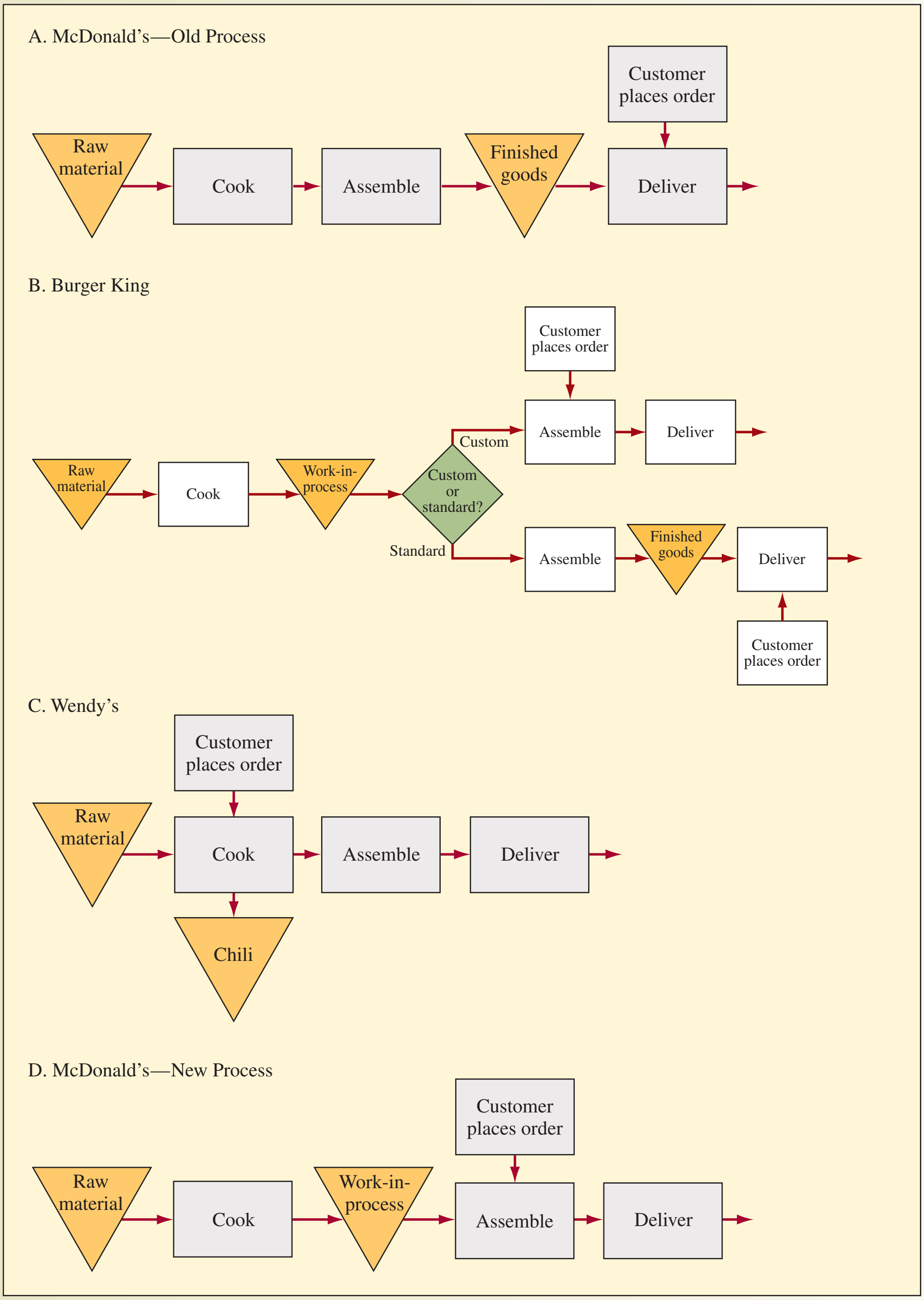
This **make-to-order** process is activated only in response to an actual order. Inventory (both work-in-process and finished goods) is kept to a minimum. Theoretically, one would expect that response time would be slow because all the activities need to be completed before the product is delivered to the customer. Services by their very nature often use make-to-order processes. A make-to-order process is used for products in the project and job shop part of the diagonal in the product process matrix, i.e., for customized products produced in low volumes.

McDonald's revolutionized the hamburger-making process by developing a high-volume approach. A diagram of McDonald's traditional process is shown in Exhibit 6.2A. Until recently, hamburgers were grilled in batches. Standard hamburgers (for example, the "Big Mac" consists of two beef patties, sauce, lettuce, cheese, pickles, and onion on a sesame seed bun) were then prepared and stored in a holding bin for immediate delivery to the customer. A person who judged current demand and placed orders to keep inventory in the bin at an appropriate level controlled the whole process. This is a highly efficient **make-to-stock** process that produces standard products that can be delivered quickly to the customer. This quick process appeals to families with small children, for whom speed of delivery is important.

In general, a make-to-stock process ends with finished goods inventory; customer orders are then served from this inventory. A make-to-stock process can be controlled based on the actual or anticipated amount of finished goods inventory. A target stocking level, for example, might be set, and the process would be periodically activated to maintain that target stocking level. Make-to-stock processes are also used when demand is seasonal. In this case, inventory can be built during the slow season and used during

Making Hamburgers at McDonald's, Burger King, and Wendy's

EXHIBIT 6.2



the peak season, thus allowing the process to run at a constant rate throughout the year. Make-to-stock processes are used for products in the assembly line and continuous process part of the product process matrix, i.e., those products with high volume but little customization.

The unique feature of the Burger King process, shown in Exhibit 6.2B, is a highly specialized conveyor–broiler. Raw hamburger patties are placed on a moving conveyor that runs through a flaming broiler. In exactly 90 seconds, the patties are cooked on both sides with a unique broiler taste. Due to the fixed time for a patty to move through the conveyor–broiler, the thickness of the patties must be the same for all the hamburger products. The buns are also warmed on a conveyor. This system results in a unique, highly consistent product. The cooked patties are stored in a warmed storage container. During periods of high demand, some standard hamburgers are prepared and inventoried for immediate delivery. Custom hamburgers with unique combinations of condiments are prepared to order. This *hybrid* process provides flexibility to respond to customer preferences through the assemble-to-order backend process—thus, the Burger King "have it your way" slogan. In general, **hybrid** processes combine the features of both make-to-order and make-to-stock. Here, two types of process are parallel alternatives at the end of the Burger King process.

Modularized products are made using a hybrid process. In modularized products, generic components (sub-assemblies or modules) are first made-to-stock. The components are then assembled in different combinations, when actual customer demand occurs. As shown in the OSMP, a company like Silent Witness is able to offer more than 1000 different end products, with fewer than 40 standard modules. Modularization thus uses the characteristics of both make-to-order and make-to-stock processes.

Modularization is also related to **mass customization**. Mass customization implies that mass production methods (high volume process for the modules with the advantages discussed in Chapter 5) are employed, while at the same time offering customization (assembling the standard modules into many different end products). Mass customization is discussed in more detail in Chapter 8.

A key trade-off in modularization is the speed of design, quality, and reliability versus uniqueness. For example, while Mercedes realized that while having every model as unique as possible (differentiating between the various models) was important to a luxury car brand, having too many unique parts in each model can bring its own problems. Designing unique parts requires increasing the time needed to design a new model. This could be a disadvantage if a competitor like Lexus or BMW introduces a state-of-the art model more quickly. Also, new and untested parts have a higher risk of unanticipated failure in the field, resulting in product recalls, whereas using common parts that have already been field tested would be more reliable. At the same time, though, Mercedes wants to keep its reputation for innovation in each model. Thus, it does not want too many common components either. So Mercedes is using limited modularization.[1]

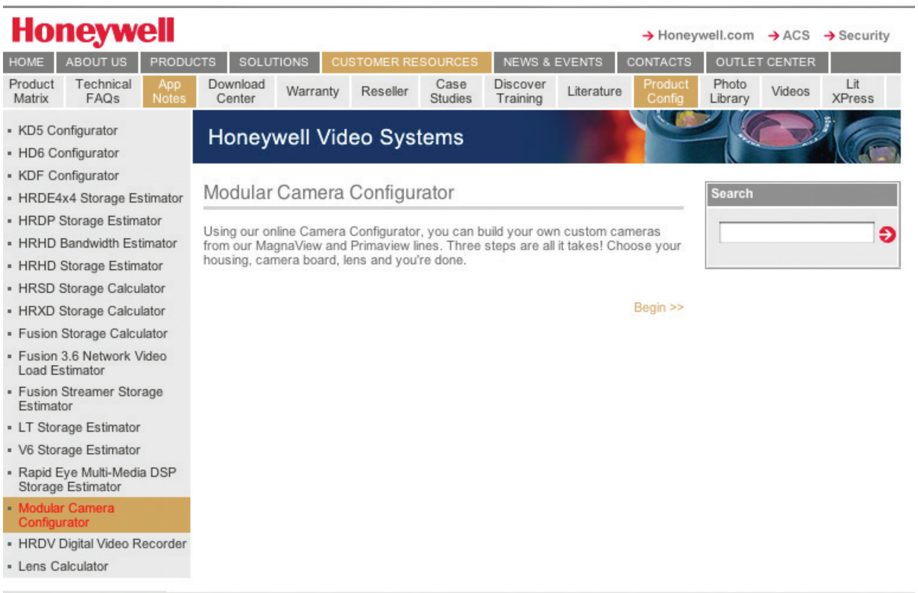
Continuing with our tour, Wendy's uses a make-to-order process (as shown in Exhibit 6.2C) that is in full view of the customer. Hamburger patties are cooked on a grill. During high-volume times, the cook tries to get a little ahead and anticipates the arrival of customers. Patties that are on the grill too long are used in the chili soup. When a customer order arrives, a patty is taken from the grill and the hamburger is assembled to the exact specifications of the customer. Because the process starts with the cooking of the patty, it is a little slower. The customer can see what is going on, and the perception is of a high-quality custom product.

Operations and Supply Management in Practice

Design Your Own Surveillance Camera on the Web

Founded in 1986 and based in Surrey, British Columbia, Silent Witness (now a unit of Honeywell Video Systems), is a company that designs and manufactures a full range of video monitoring technology for the global marketplace, including high-performance closed circuit television (CCTV) cameras, digital and analog storage solutions, digital processing technologies, and network-based remote video surveillance. You can design your preferred surveillance camera by going to the Silent Witness Web site. With about 19 types of housings, 12 types of cameras, and 6 types of lenses (each for two different types of television systems), and some other options, you can have more than 1000 camera configurations, yet the company needs to produce and carry only a little more than 40 stock keeping units (SKUs). So they don't have to forecast demand and manage the supply chain for 1000 items, only for 40. This is a good example of how modular design gives the customer more choices while making operations management easier for the provider.

■ Source: www.honeywellvideo.com/support/configurations/modular



Finally, the new McDonald's process introduced in 1999 (Exhibit 6.2D) is a hybrid process. Cooked hamburger patties are inventoried in a special storage device that maintains the moistness of the cooked patties for up to 30 minutes. The process makes extensive use of the latest cooking technologies. Hamburger patties are cooked in less than 45 seconds. Buns are toasted in only 11 seconds. Individual items on each customer order are transmitted immediately to the area where the hamburgers are assembled, using a specially designed computer system. The assembly process that includes toasting the buns is designed to respond to a customer order in only 15 seconds. By combining the latest technology and clever process engineering, McDonald's has developed a very quick response process. The product is fresh, delivered quickly, and made to the exact specifications of the customer.

Each of the processes used by these companies has its strengths and weaknesses. McDonald's is the high-volume leader, catering to families with young children. Burger

King has its unique taste. Wendy's appeals to those who want their hamburgers prepared the old-fashioned way. Each company focuses advertising and promotional efforts toward attracting the segment of the market its process characteristics best support.

One final method for categorizing a process is by whether it is paced or nonpaced. Recall that Burger King uses the conveyor–broiler to cook hamburgers in exactly 90 seconds. **Pacing** refers to the fixed timing of the movement of items through the process. In a serial process, the movement of items through each activity (or stage) is often paced in some mechanical way to coordinate the line. An assembly line may, for example, move every 45 seconds. Another mechanism used is a clock that counts down the amount of time left in each cycle. When the clock reaches zero, the parts are manually moved to the next activity. Dividing the time available to produce a certain product by customer demand for the product calculates the required cycle time for a process. For example, if an automobile manufacturer needs to produce 1000 automobiles during a shift where the assembly line operates 420 minutes, the cycle time is 25.2 seconds (420 minutes/1000 automobiles $\times$ 60 seconds/minute $=$ 25.2 seconds/automobile).

MEASURING PROCESS PERFORMANCE

There is much variation in the way performance metrics are calculated in practice. This section defines metrics in a manner consistent with the most common use in practice. It is vital, though, to understand exactly how a metric coming from a particular company or industry is calculated prior to making any decisions. It would be easier if metrics were calculated more consistently, but this is just not the case. So, if a manager says that his utilization is 90 percent or her efficiency is 115 percent, a standard follow-up question is "How did you calculate that?" Metrics are often calculated in the context of a particular process. Metrics used in cases that you are studying may be defined slightly differently from what is given here. It is important to understand, within the context of the case, how a term is being used.

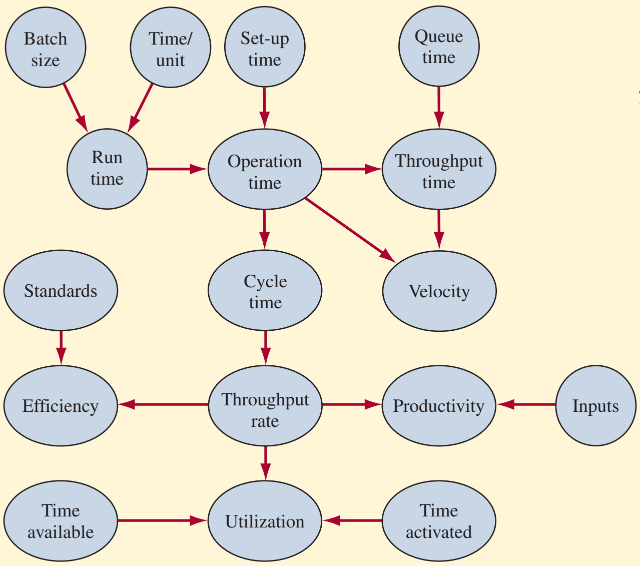
Comparing the metrics of one company to another, often referred to as *benchmarking,* is an important activity. Metrics tell a firm if progress is being made toward improvement. Similar to the value of financial measures to accountants, process performance metrics give the operations manager a gauge on how productively a process is currently operating and how productivity is changing over time. Often, operations managers need to improve the performance of a process or project the impact of a proposed change. The metrics described in this section are important for answering these questions. To help in understanding these calculations, Exhibit 6.3 shows how these metrics relate to one another.

Possibly the most common process metric is utilization. As discussed earlier in the chapter, utilization is the ratio of the time that a resource is actually being used relative to the time that it is available for use. Utilization is always measured in reference to some resource—for example, the utilization of direct labour or the utilization of a machine resource. The distinction between productivity and utilization is important.

Productivity is the ratio of output to input. Total factor productivity is usually measured in monetary units, dollars, for example, by taking the dollar value of the output (such as goods and services sold) and dividing by the cost of all the inputs (that is, material, labour, and capital investment). Alternatively, *partial factor productivity* is measured based on an individual input, labour being the most common. Partial factor productivity answers the question of how much output we can get from a given level of input; for example, how many computers are made per employee working in the computer manufacturing plant. (See Chapter 2 for additional information about productivity.) Utilization measures the

Process Performance Metrics

EXHIBIT 6.3



$$\textit{Operation time} = \textit{Set-up time} + \textit{Run time}$$

$$\textit{Throughput time} = \textit{Average time for a unit to move through the system}$$

$$\textit{Velocity} = \frac{\textit{Throughput time}}{\textit{Value-added time}}$$

$$\textit{Cycle time} = \textit{Average time between completion of units}$$

$$\textit{Throughput rate} = \frac{1}{\textit{Cycle time}}$$

$$\textit{Efficiency} = \frac{\textit{Actual output}}{\textit{Standard output}}$$

$$\textit{Productivity} = \frac{\textit{Output}}{\textit{Input}}$$

$$\textit{Utilization} = \frac{\textit{Time activated}}{\textit{Time available}}$$

actual activation of the resource. For example, what is the percentage of time that an expensive machine is actually operating?

Efficiency is a ratio of the actual output of a process relative to some standard. For example, consider a machine designed to package cereal at a rate of 30 boxes per minute. If, during a shift, the operators actually produce at a rate of 36 boxes per minute, then the efficiency of the machine is 120 percent (36/30). An alternative way to use the term *efficiency* is to measure the loss or gain in a process. For example, if 1000 units of energy are put into a process designed to convert that energy to some alternative form, and the process produces only 800 units of energy in the new form, then the process is 80 percent efficient.

Run time is the time required to produce a batch of parts. This is calculated by multiplying the time required to produce each unit by the batch size. The **set-up time** is the time required to prepare a machine to make a particular item. Machines that have significant set-up time will typically run parts in batches. The **operation (process) time** is the sum of the set-up time and run time for a batch of parts that are run on a machine. Consider the cereal-boxing machine that is designed to produce at a rate of 30 boxes per minute. The run time for each box is 2 seconds. To switch the machine from 500 g boxes to 250 g boxes requires a set-up time of 30 minutes. The operation time to make a batch of 10 000 250 g boxes is 21 800 seconds (30 minutes' set-up $\times$ 60 seconds/minute + 2 seconds/box $\times$ 10 000 boxes), or 363.33 minutes.

In practice, set-up time is often not included in the utilization of the process. In essence, set-up time is categorized like the downtime caused by repair or some other disruption to the process. This assumption can vary from company to company, so it is important when comparing the utilization of a machine or other resource to understand exactly how the company categorizes set-up time.

Another related term is **throughput time**. Throughput time includes the time that the unit spends actually being worked on together with the time spent waiting in a queue. As a simple example, consider a paced assembly line that has six stations and runs with a cycle time of 30 seconds. If the stations are located one right after another and every 30 seconds parts move from one station to the next, then the throughput time is three minutes (30 seconds × 6 stations/60 seconds per minute). The **throughput rate** is the output rate that the process is expected to produce over a period of time. The throughput rate of the assembly line is 120 units per hour (60 minutes/hour × 60 seconds/minute ÷ 30 seconds/unit). In this case, the throughput rate is the mathematical inverse of the cycle time. Sometimes throughput time and cycle time are used interchangeably (recall that cycle time is related to the operation time at the bottleneck). So in practice it is important to determine how the term is being used in the context of the process being studied. In this text, cycle time and throughput time are considered to be different.

It has been long recognized that cycle time depends on the bottleneck and that managing the bottleneck is important in ensuring the effectiveness of a process. In fact, in Chapter 3, the "critical path" in a project schedule is the bottleneck in the process since it determines when the project can be completed. Thus, the chapter emphasized the importance of managing the critical path. Lean Manufacturing (Chapter 10) and more recently the Theory of Contraints[2] have also reiterated the importance of bottlenecks in process management.

Often, units are not worked on 100 percent of the time as they move through a process. Because the cycle time of the individual parts of a process often varies, buffers are incorporated in the process to allow individual activities to operate independently, at least to some extent. In the six-station assembly line just described, consider the impact of having 10 additional buffer positions along the line. Assume that two of these positions are between the first and second workstations, two are between stations 2 and 3, and so forth. If these positions are always occupied, then the average throughput time would be eight minutes (assuming a total of 16 positions along the assembly line and an average cycle time of 30 seconds).

A cereal production line running a particular package size. Changing the package size would entail a set-up during which the production line would be idle. To minimize this idle time, each package size is produced in large batches, often called a lot size.

Process velocity (also known as **throughput ratio**) is the ratio of the total throughput time to the value-added time. **Value-added time** is the time in which useful work is actually being done on the unit. Assuming that all of the activities that are included in the process are value-added activities, value-added time should be the sum of the activity operation times in the process. The process velocity (or throughput ratio) for our assembly line with the 10 additional buffer positions, assuming the positions are used 100 percent of the time, is 2.66 (8 minutes/3 minutes).

Summary

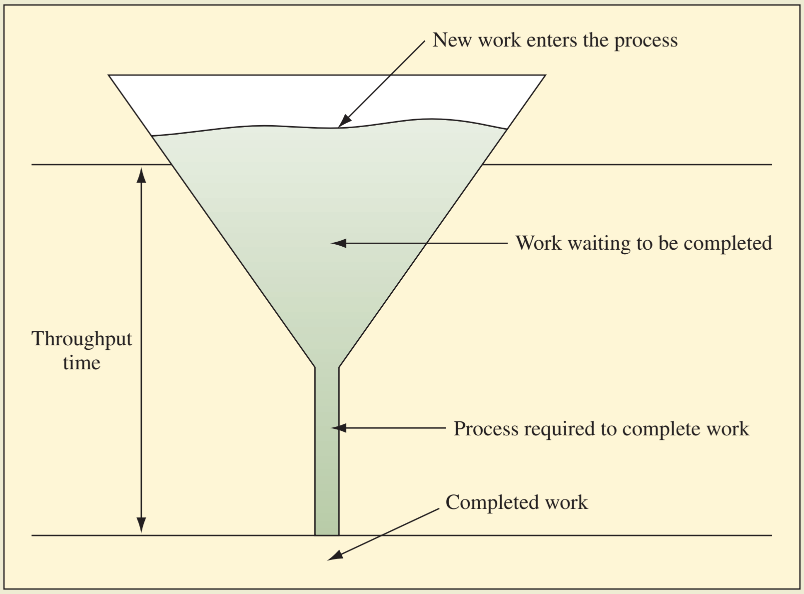
Process analysis is a basic skill you need to understand how a business operates. You can obtain great insight by drawing a simple flowchart showing the flow of materials or information through an enterprise. The diagram should include all the operating elements and show how they fit together. Be sure to indicate where material is stored or where orders are queued. Often, 90 percent or more of the time required for a customer to be served is spent just waiting. Hence, merely eliminating the waiting time can dramatically improve the performance of the process.

Remember this fundamental concept when analyzing a process: What goes into the process must come out of the process. A process taken as a whole is like the funnel shown in Exhibit 6.4. The outlet of the funnel restricts the amount that can flow through. In a real business process, certain resources limit output. If liquid is poured into the funnel at a rate greater than it can exit, the level in the funnel will continue to grow. As the level of liquid in the funnel grows, the time it takes the liquid to flow through the funnel increases. If too much liquid is poured into the funnel, it just spills over the top and never flows through.

The same is true of a real process. If too many jobs are pumped into the process, the time that it takes to complete a job will increase because the waiting time will increase. At some point, customers will go somewhere else and the business will be lost. When a process is operating at capacity, the only way to take on more work without increasing the waiting time is to add more capacity. This requires finding what activity is limiting the output of the process and increasing the capacity of that activity. In essence, the tube leading out of the funnel needs to be made larger.

What Goes into a Process Must Come Out of the Process. Input Rate Must Be Less Than or Equal to the Output Rate; Otherwise, the System Will Overflow.

EXHIBIT 6.4



Key Terms

Blocking The activities in the stage must stop because there is no place to deposit the item just completed.

Bottleneck A stage or activity (or resource) that limits the capacity or maximum output of the process.

Buffering A storage area between stages where the output of a stage is placed prior to being used in a downstream stage. Buffering allows the stages to operate independently.

Cycle time The average time between completions of successive units in a process (this is the definition used in this book). The term is sometimes used to mean the elapsed time between starting and completing a job (throughput time).

Efficiency A ratio of the actual output of a process relative to some standard.

Hybrid Combines the features of both make-to-order and make-to-stock. Typically, generic components are made and stocked at some point in the process. These generic components are customized in a final process to meet actual orders.

Make-to-order A process that is activated only in response to an actual order.

Make-to-stock A process that produces standard products that are stored in finished goods inventory. The product is delivered quickly to the customer from the finished goods inventory.

Mass customization Providing customized end products while at the same time using the efficiencies of a high volume manufacturing process.

Modular products Products that are assembled into different end products from standard modules (components).

Operation time The sum of the set-up time and run time for a batch of parts that are run on a machine.

Pacing Movement of items through a process is coordinated through a timing mechanism. Most processes are not paced, but assembly lines are usually paced.

Process Any set of activities performed by an organization that takes inputs and transforms them into outputs, ideally of greater value to the organization than the original inputs.

Process velocity or throughput ratio The ratio of the total throughput time to the value-added time.

Productivity The ratio of output to input. Taking the dollar value of the output and dividing by the dollar value of the inputs usually measures total factor productivity. Alternatively, *partial factor productivity* is measured based on an individual input and often is not calculated using dollar values (an example would be units/person).

Run time The time required to produce a batch of parts.

Set-up time The time required to prepare a machine to make a particular item.

Starving The activities in a stage must stop because there is no work.

Throughput rate The output rate that the process is expected to produce over a period of time.

Throughput time The average time that it takes a unit to move through an entire process. Usually, the term *lead time* is used to refer to the total time that it takes a customer to receive an order (includes time to process the order, throughput time, and delivery time).

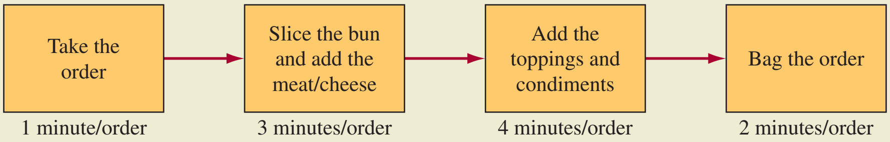
Utilization The ratio of the time that a resource is actually activated relative to the time that it is available for use.

Value-added time The time in which useful work is actually being done on the unit.

Value stream mapping Visually describing a process and analyzing it for improvement.

Solved Problems

Daffy Dave's Sub Shop makes custom submarine sandwiches to order. Dave is analyzing the processes at the shop. The general flow of the process is shown below. A separate person works at each of the steps in the process.



Daffy Dave wants to figure out the following for a typical 8-hour work day.

a. What is the current maximum output of the process?
b. If we add another person, where would we add him or her and what is the benefit?
c. Is there a benefit if we can shift 1 minute from Bun and Meat to Order Taking? Assume we do not make the change in part *b* above.
d. Is there a benefit if we shift 1 minute of work from Condiments to Bagging? Assume we do not make the changes in parts *b* and *c* above.

SOLUTION

a. Maximum output is 120 subs per day.

OPERATION	OUTPUT
Take Orders	(60 min. per hour/1 min. per order) * 8 hours = 480 subs per day
Bun and Meat	(60 min. per hour/3 min. per order) * 8 hours = 160 subs per day
Toppings/Condiments	(60 min. per hour/4 min. per order) * 8 hours = 120 subs per day
Bag the Order	(60 min. per hour/2 min. per order) * 8 hours = 240 subs per day

Output per day is determined by the slowest station; therefore, we can only produce 120 per day because that is the limit of the Toppings/Condiments station.

b. Dave should add the person to the slowest station (Condiments/Toppings) since it is the bottleneck.

OPERATION	OUTPUT
Take Orders	480 subs per day
Bun and Meat	160 subs per day
Toppings/Condiments	120 * 2 = 240 subs per day
Bag the Order	240 subs per day

The impact is not a very big one. Even though the Toppings/Condiments station now can do 240 subs per day, the Bun and Meat station can only do 160, so that is the maximum output.

c. Order Taking station will go from 1 minute to 2 minutes, and Bun and Meat goes from 3 minutes to 2 minutes.

OPERATION	OUTPUT
Take Orders	(60 min. per hour/2 min. per order) * 8 hours = 240 subs per day
Bun and Meat	(60 min. per hour/2 min. per order) * 8 hours = 240 subs per day
Toppings/Condiments	(60 min. per hour/4 min. per order) * 8 hours = 120 subs per day
Bag the Order	(60 min. per hour/2 min. per order) * 8 hours = 240 subs per day

There is no benefit to this change. Dave can still only make 120 subs per day since we can only produce 120 per day because that is the limit of the Toppings/Condiments station.

d. Toppings/Condiments station will go from 4 minutes to 3 minutes, and Bagging goes from 2 minutes to 3 minutes.

OPERATION	OUTPUT
Take Orders	(60 min. per hour/1 min. per order) * 8 hours = 480 subs per day
Bun and Meat	(60 min. per hour/3 min. per order) * 8 hours = 160 subs per day
Toppings/Condiments	(60 min. per hour/3 min. per order) * 8 hours = 160 subs per day
Bag the Order	(60 min. per hour/3 min. per order) * 8 hours = 160 subs per day

There is a benefit to this change. Dave can now make 160 subs per day. This will provide the same benefit as hiring another worker. However, if Dave wants to increase output further, he will have to hire some additional staff.

Review and Discussion Questions

1. Compare McDonald's old and new processes for making hamburgers. How valid is McDonald's claim that the new process will produce fresher hamburgers for the customer? Comparing McDonald's new process to the processes used by Burger King and Wendy's, which process appears to produce the freshest hamburgers?
2. Explain how having more work-in-process inventory can improve the efficiency of a process. How can this be bad?
3. Recently, some operations management experts have begun insisting that simply minimizing process velocity, which actually means minimizing the time that it takes to process something through the system, is the single most important measure for improving a process. Can you think of a situation in which this might not be true?
4. What is a bottleneck and how does it help manage a process?
5. What are the advantages and disadvantages of a modularized process compared to make-to-stock and make-to-order processes?
6. For what type of products or services would it not be appropriate to use a hybrid process?
7. Give an example of a process where you have observed a reduction in set-up time through the use of better technology or better techniques. How has this set-up time reduction helped?

Problems[3]

1. Osakwe, an enterprising student, has set up an internship clearinghouse for business students. Each student who uses the service fills out a form and lists up to 10 companies that he or she would like to have contacted. The clearinghouse has a choice of two methods to use for processing the forms. The traditional method requires about 20 minutes to review the form and arrange the information in the proper order for processing. Once this set-up is done, it takes only two minutes per company requested to complete the processing. The other alternative uses an optical scan/retrieve system, which takes only a minute to prepare but requires five minutes per company for completing the processing. If it costs about the same amount per minute for processing with either of the two methods, when should each be used?
2. Rockness Recycling refurbishes rundown business students. The process uses a moving belt, which carries each student through the five steps of the process in sequence. The five steps are as follows:

STEP	DESCRIPTION	TIME REQUIRED PER STUDENT
1	Unpack and place on belt	1.0 minute
2	Strip off bad habits	1.5 minutes
3	Scrub and clean mind	0.8 minute
4	Insert modern methods	1.0 minute
5	Polish and pack	1.2 minutes

One faculty member is assigned to each of these steps. Faculty members work a 40-hour week and rotate jobs each week. Mr. Rockness has been working on a contract from General Eclectic, which requires delivery of 2000 refurbished students per week. A representative of the human resources department has just called, complaining that the company hasn't been receiving the agreed-upon number of students. A check of finished goods inventory by Mr. Rockness reveals that there is no stock left. What is going on?

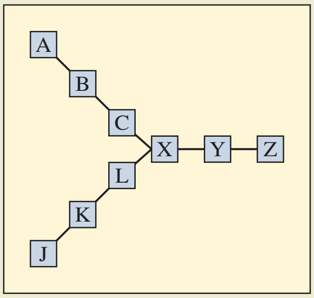
3. A local market research firm has just won a contract for several thousand small projects involving data gathering and statistical analysis. In the past, the firm has assigned each project to a single member of its highly trained professional staff. This person would both gather and analyze the data. Using this approach, an experienced person can complete an average of 10 such projects in an eight-hour day.

   The firm's management is thinking of assigning two people to each project in order to allow them to specialize and become more efficient. The process would require the data gatherer to fill out a matrix on the computer, check it, and transmit it to the statistical analysis program for the analyst to complete. Data can be gathered on one project while the analysis is being completed on another, but the analysis must be complete before the statistical analysis program can accept the new data. After some practice, the new process can be completed with a standard time of 20 minutes for the data gathering and 30 minutes for the analysis.

   a. What is the production (output per hour) for each alternative? What is the productivity (output per labour hour)?

   b. How long would it take to complete 1000 projects with each alternative? What would the labour content (total number of labour hours) for 1000 projects be for each alternative?

4. The following represents a process used to assemble a chair with an upholstered seat. Stations A, B, and C make the seat; stations J, K, and L assemble the chair frame; station X is where the two subassemblies are brought together; and some final tasks are completed in stations Y and Z. One worker is assigned to each of the stations. Generally, no inventory is kept anywhere in the system, although there is room for one unit between each of the stations that might be used for a brief amount of time.



Given the following amount of work in seconds required at each station:

A	38	J	32	X	22
B	34	K	30	Y	18
C	35	L	34	Z	20

   a. What is the possible daily output of this "process" if 8 hours of processing time is available each day?

   b. Given your output rate in part *a*, what is the efficiency of the process?

   c. What is the throughput time of the process?

5. Wally's Widget Warehouse takes orders from 7 a.m. to 7 p.m. The manager wants to analyze the process. There are three steps required to ship a customer order. The first step is to take the order from a customer (capacity: 100 customers/hr). The second step is to pick the order for the customer (capacity: 80 customers/hr), and then the warehouse has to pack the order ready for shipping (capacity: 60 customers/hr). Wally promises that every order placed today gets shipped tomorrow. That means that the picking and packing operations must finish all orders before they go home.

   Wally wants to figure out the following.

   a. Draw the flowchart of the process from customer order placement to shipping

   b. What is the current maximum output of the process assuming that no one works overtime?

   c. How long will the picking and packing operations have to work if we have a day where the order taker works at his maximum capacity?

   d. Given *c*, what is the maximum number of orders waiting to be picked?

   e. Given *c*, what is the maximum number of orders waiting to be packed?

   f. If we double the packing capacity (from 60 to 120 orders per hour), what impact does this have on your answers in parts *c, d*, and *e*?

6. Anvi, the manager of a bakery, is interested in analyzing her bread-making process. The raw materials required for making bread are carried in inventory. Two steps are required in preparing the bread. The first is preparing the dough and baking the loaves, here referred to as bread making. The second is packaging the loaves. Due to the size of the mixers in the bakery, bread is made in batches of 100 loaves. A batch of 100 loaves is baked every hour. The loaves are then put into an intermediate stocking area ready for packing. Packaging needs only 0.75 hour to place the 100 loaves in bags. The loaves are then stored, waiting for shipment

   Anvi is considering buying an additional bread-making machine (though not an additional packaging machine). The time for each individual bread-making operation is still one hour per 100 loaves. Assume that the bakery can sell all it can bake.[4]

   a. Draw flowcharts for the situations with both one and two bread-making machines.

   b. When there is only one bread-making machine what is the capacity of the bakery per hour? What are the utilizations of the bread-making and packing operations?

   c. When there are two bread-making machines what is the capacity of the bakery per hour? What are the utilizations of the bread-making and packing operations?

CASE 1 Kristen's Cookie Company (A)

You and your roommate are preparing to start Kristen's Cookie Company in your on-campus apartment. The company will provide fresh cookies to starving students late at night. You need to evaluate the preliminary design for the company's production process to figure out many variables there are, including what prices to charge, whether you will be able to make a profit, and how many orders to accept.

Business Concept

Your idea is to bake fresh cookies to order, using any combination of ingredients that the buyer wants. The cookies will be ready for pickup at your apartment within an hour.

Several factors will set you apart from competing products such as store-bought cookies. First, your cookies will be completely fresh. You will not bake any cookies before receiving the order; therefore, the buyer will be getting cookies that are literally hot out of the oven.

Second, like Steve's Ice Cream,[5] you will have a variety of ingredients available to add to the basic dough, including chocolate chips, M&M's, Crispy Crunch bars, coconut, walnuts, and raisins. Buyers will telephone in their orders and specify which of these ingredients they want in their cookies. You guarantee completely fresh cookies. In short, you will have the freshest, most exotic cookies anywhere, available right on campus.

The Production Process

Baking cookies is simple: mix all the ingredients in a food processor; spoon out the cookie dough onto a tray; put the cookies into the oven; bake them; take the tray of cookies out of the oven; let the cookies cool; and, finally, take the cookies off the tray and carefully pack them in a box. You and your roommate already own all the necessary capital equipment: one food processor, cookie sheets, and spoons. Your apartment has a small oven that will hold one tray at a time. Your landlord pays for all the electricity. The variable costs, therefore, are merely the cost of the ingredients (estimated to be $0.60/dozen), the cost of the box in which the cookies are packed ($0.10 per box; each box holds a dozen cookies), and your time (what value do you place on your time?).

A detailed examination of the production process, which specifies how long each of the steps will take, follows. The first step is to take an order, which your roommate has figured out how to do quickly and with 100 percent accuracy. (Actually, you and your roommate devised a method using the Internet to accept orders and to inform customers when their orders will be ready for pickup. Because this runs automatically on your personal computer, it does not take any of your time.) Therefore, this step will be ignored in further analysis.

You and your roommate have timed the necessary physical operations. The first physical production step is to wash out the mixing bowl from the previous batch, add all of the ingredients, and mix them in your food processor. The mixing bowls hold ingredients for up to three dozen cookies. You then dish up the cookies, one dozen at a time, onto a cookie tray. These activities take six minutes for the washing and mixing steps, regardless of how many cookies are being made in the batch. That is, to mix enough dough and ingredients for two dozen cookies takes the same six minutes as one dozen cookies. However, dishing up the cookies onto the sheet takes two minutes per sheet.

The next step, performed by your roommate, is to put the cookies in the oven and set the thermostat and timer, which takes about one minute. The cookies bake for the next nine minutes. So total baking time is 10 minutes, during the first minute of which your roommate is busy setting the oven. Because the oven holds only one cookie sheet, a second dozen take an additional 10 minutes to bake.

Your roommate also performs the last steps of the process by first removing the cookies from the oven and putting them aside to cool for five minutes, then carefully packing them in a box and accepting payment. Removing the cookies from the oven takes only a negligible amount of time, but it must be done promptly. It takes two minutes to pack each dozen and about one minute to accept payment for the order.

That is the process for producing cookies by the dozen in Kristen's Cookie Company. As experienced bakers know, a few simplifications were made in the actual cookie production process. For example, the first batch of cookies for the night requires preheating the oven. However, such complexities will be put aside for now. Begin your analysis by developing a process flow diagram of the cookie-making process.

Key Questions to Answer Before You Launch the Business

To launch the business, you need to set prices and rules for accepting orders. Some issues will be resolved only after you get started and try out different ways of producing the cookies. Before you start, however, you at least want a preliminary plan, with as much as possible specified, so that you can do a careful calculation of how much time you will have to devote to this business each night, and how much money you can expect to make. For example, when you conduct a market survey to determine the likely demand, you will want to specify exactly what your order policies will be. Therefore, answering the following operational questions should help you:

1. How long will it take you to fill an order?
2. How many orders can you fill in a night, assuming you are open four hours each night?
3. How much of your own and your roommate's valuable time will it take to fill each order?
4. Because your cookie sheets can hold exactly one dozen cookies, you will produce and sell cookies by the dozen. Should you give any discount for people who order two dozen cookies, three dozen cookies, or more? If so, how much? Will it take you any longer to fill a two-dozen cookie order than a one-dozen cookie order?
5. How many food processors and cookie sheets will you need?
6. Are there any changes you can make in your production plans that will allow you to make better cookies, or more cookies in less time or at lower cost? For example, is there a bottleneck operation in your production process that you can expand cheaply? What is the effect of adding another oven? How much would you be willing to pay to rent an additional oven?

Questions

1. What happens if you are trying to do this by yourself without a roommate?
2. Should you offer special rates for rush orders? Suppose you have just put a sheet of cookies into the oven and someone calls up with a "crash priority" order for a dozen cookies of a different flavour. Can you fill the priority order while still fulfilling the order for the cookies that are already in the oven? If not, how much of a premium should you charge for filling the rush order?
3. When should you promise delivery? How can you look quickly at your order board (list of pending orders) and tell a caller when his or her order will be ready? How much of a safety margin for timing should you allow?
4. What other factors should you consider at this stage of planning your business?
5. Your product must be made to order because each order is potentially unique. If you decide to sell standard cookies instead, how should you change the production system? The order-taking process?

Source: Kristen's Cookie Company (A), Case 9-686-093, Written by Roger Bohn.

CASE 2 Canadian Blood Services (CBS)[1]

Canadian Blood Services is a not-for-profit organization created in 1998 that manages the blood supply for Canadians on behalf of the government.[2] It often organizes blood drives in local communities, setting up a temporary blood collection centre in places like gymnasiums. The process of blood collection at such places is as follows: When a potential donor arrives, his or her name and address are recorded manually and he or she is assigned a number in order of arrival. Donors are also given a card with their name on it. Donors then wait in a queue till their number is called. At that time, a nurse records and verifies details about the donor. The nurse also pricks the donor's finger, using a special needle to draw blood into a mini-test tube. Both needle and test tube are disposable. This blood sample is tested immediately for sufficient iron. If donors pass this test, they are given a questionnaire to fill out. This questionnaire elicits information on any current illnesses and recent travel. After completing the questionnaire, donors drop the card obtained upon arrival into a box, which ensures first-drop-first-called sequence. Donors then wait with the questionnaire until their card is taken out of the box and their name is called. A nurse goes through the questionnaire with the donor to ensure eligibility. For example, if a person has travelled to a region with malaria in the last year, they are ineligible to donate blood (even if they did not contract malaria). On a busy day, potential donors can spend more than an hour in the system before being sent back because they are ineligible. This has caused a lot of annoyance to potential donors. Some have commented that they would not return even when eligible.

1. Draw a flow chart of the process. Times are not necessary.
2. How might you improve the process to avoid wasting the time of ineligible donors? Would there be any material cost savings?
3. If you could do some market intelligence on the community, such as income or ethnicity or any other relevant information, what might you do at the collection centre or other point to expeditiously weed out ineligible donors?

[1]This case is adopted from a real situation observed at a CBS blood collection drive.
[2]*Source:* www.bloodservices.ca

Footnotes

[1]Stephen Power, "Betting on the S; Mercedes Looks to New Model Of Flagship S-Class to Reverse An Image of Sagging Quality," *Wall Street Journal*, July 11, 2005. p. B.1.
[2]Eliyahu Goldratt, *Theory of Constraints* (Great Barrington MA: North River Press, 1990).
[3]The authors are indebted to D. Clay Whybark of the University of North Carolina for contributing Problems 1–3.
[4]This example is similar to one given by A. E. Gray in "Capacity Analysis: Sample Problems," *Harvard Business School* 9-696-058.
[5]Steve's Ice Cream was started in the Boston area by a young entrepreneur to provide make-to-order ice cream, using mix-ins.

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Gray, A.E., and J. Leonard. "Process Fundamentals." *Harvard Business School* 9-696-023.

Jeston, J., and J. Nelis. *Business Process Management: Practical Guidelines to Successful Implementation*. Burlington, MA: Butterworth-Heinemann, 2006.