CSCMP
COUNCIL OF SUPPLY CHAIN MANAGEMENT PROFESSIONALS

THE DEFINITIVE GUIDE TO MANUFACTURING AND SERVICE OPERATIONS

Master the Strategies and Tactics for Planning, Organizing, and Managing How Products and Services Are Produced

Council of Supply Chain Management Professionals and

Nada Sanders

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Council of Supply Chain
Management Professionals
and
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Dedicated to all students who want to learn how the "engine of business" works.

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Nada Sanders is Iacocca Chair and Professor of Supply Chain Management at Lehigh University. She is an internationally recognized expert in the area of business forecasting and supply chain management. She received both her Ph.D. and MBA from the Ohio State University and is author of more than 100 scholarly publications. She has worked with numerous companies and is a frequently called-upon consultant, expert witness, and keynote speaker.

Founded in 1963, the **Council of Supply Chain Management Professionals** (CSCMP) is the preeminent worldwide professional association dedicated to the advancement and dissemination of research and knowledge on supply chain management. With more than 8,500 members representing nearly all industry sectors, government, and academia from 67 countries, CSCMP members are the leading practitioners and authorities in the fields of logistics and supply chain management. The organization is led by an elected group of global officers and is headquartered in Lombard, Illinois, USA.

PREFACE

Operations management is the "engine of business." It is the business function responsible for creating the goods and services companies sell. Today's fierce global competition, rapid economic changes, and advancements in both information and processing technologies have all helped place operations management in the limelight of business. Operations management is the business function that can help companies succeed in this highly competitive landscape because, without operations management, there would be no products to sell.

Operations concepts are far reaching. Operations management decisions impact every organization and are equally important to service organizations as they are to manufacturing. Operations management is also equally important in informing strategic as well as tactical decisions. This book explains the foundational concepts of operations management for both manufacturing and service operations and is intended to serve as an important resource.

1

OPERATIONS MANAGEMENT DEFINED

Defining Operations Management

Every business is managed through multiple business functions each responsible for managing certain aspects of the business. Figure 1-1 illustrates this by showing that the vice president of each of these functions reports directly to the president or CEO of the company. Marketing is responsible for sales, generating customer demand, and understanding customer wants and needs. Finance is responsible for managing cash flow, current assets, and capital investments. MIS is responsible for managing flows of information. Most of us have some idea of what finance and marketing are about, but what does operations management do?

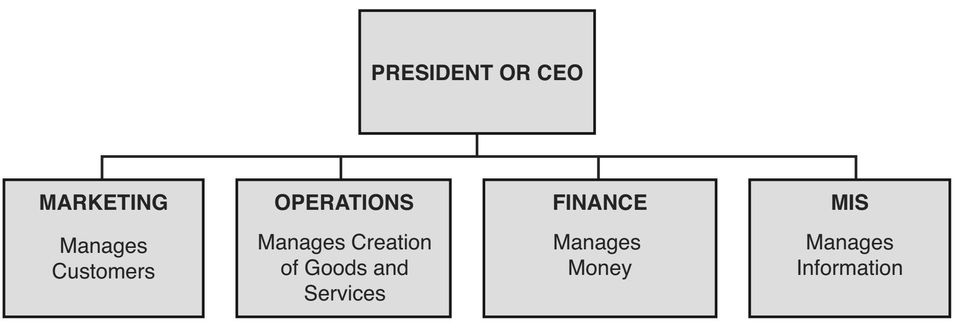

Figure 1-1 Organizational chart

Operations management (OM) is the business function responsible for managing the process of creation of goods and services. It involves planning, organizing, coordinating, and controlling all the resources needed to produce a company's goods and services. Because operations management is a management function, it involves managing people, equipment, technology, information, and all the other resources needed in the production of goods and services. Operations management is the central core function of every company. This is true regardless of the size of the company, the industry it is in, whether it is manufacturing or service, or is for-profit or not-for-profit.

Consider a pharmaceutical company such as Merck. The marketing function of Merck is responsible for promoting new pharmaceuticals to target customers and bringing customer feedback to the organization. Marketing is essentially the window to customers. The finance function of Merck makes sure that they have needed capital for different processes including R&D. However, it is the operations function that plans and coordinates all the resources needed to design, produce, and deliver the various pharmaceuticals to hospitals, pharmacies, and other locations where needed. Without operations, there would be no products to sell to customers.

The Transformation Role of Operations Management

We say that operations management performs a transformation role in the process of converting inputs such as raw materials into finished goods and services. These inputs include human resources, such as workers, staff, and managers; facilities and processes, such as buildings and equipment; they also include materials, technology, and information. In the traditional transformation model outputs are the goods and services a company produces. This is shown in Figure 1-2.

At a manufacturing plant the transformation is the physical change of raw materials into products, such as transforming steel into automobiles, cloth into jackets, or plastic into toys. This is equally true of service organizations. At a university OM is involved in organizing resources, such as faculty, curriculum, and facilities, to transform high school students into college graduates. At an airline it involves transporting passengers and their luggage from one location to another.

Figure 1-2 The transformation role of operations management

The transformation role of OM makes this function the "engine room" of the organization. As a result it is directly responsible for many decisions and activities that give rise to product design and delivery problems. The design and management of operations strongly influence how much material resources are consumed to manufacture goods or deliver a service, making sure that there is enough inventory to produce the quantities that need to be delivered to the customer, and ensuring that what is made is in fact what the customer wants. Many of these decisions can be costly. It is for this reason that OM is a function companies go to in order to improve performance and the financial bottom line.

Differences in Manufacturing Versus Service Operations

All organizations can be broadly divided into two categories: manufacturing organizations and service organizations. Although both categories have an OM function, these differences pose unique challenges for the operations function as the nature of what is being produced is different. There are two primary distinctions between these categories of organizations. First, manufacturing organizations produce a physical or tangible product that can be stored in inventory before it is needed by the customer. Service organizations, on the other hand, produce intangible products that cannot be produced ahead of time. Second, in manufacturing organizations customers typically have no direct contact with the process of production. Customer contact occurs through distributors or retailers. For example, a customer buying a computer never comes in contact with the factory where the computer is produced. However, in service organizations the customers are typically present during the creation of the service. Customers here usually come in contact with some aspect of the operation. Consider a restaurant or a barber shop, where the customer is present during the creation of the service.

The differences between manufacturing organizations and service organizations are typically not as clear-cut as they might appear in the preceding example. Usually there is much overlap between them, and their distinctions are increasingly becoming murky. Most manufacturers provide services as part of their business, and many service firms manufacture physical goods they use during service delivery. For example, a manufacturer of jet engines, such as Rolls Royce, not only produces engines but services them. A barber shop may sell its own line of hair care products.

We can further divide a service operation into high contact and low contact segments. High contact segments are those parts of the operation where the customer is present, such as the service area of the post office or the dining area of a restaurant. However, these services also have a low contact segment. These can be thought of as "back room" or "behind the scenes" segments. Examples would include the kitchen segment at a fast-food restaurant or the laboratory for specimen analysis at a hospital.

Finally, in addition to pure manufacturing and pure service, there are companies that have some characteristics of each type of organization. It is difficult to tell whether these companies are actually manufacturing or service organizations. An excellent example is an automated warehouse or a mail-order catalog business. These businesses have low customer contact and are capital intensive. They are most like manufacturing organizations yet they provide a service. We call these companies *quasi-manufacturing organizations*.

The operational requirements of these two types of organizations are different, from labor to inventory issues. These differences are shown in Table 1-1. As a result, it is important to understand how to manage both service and manufacturing operations.

Table 1-1 Comparing Manufacturing and Service Operations

Manufacturers	Services
Tangible product.	Intangible product.
Product can be inventoried.	Product cannot be inventoried.
Low customer contact.	High customer contact.
Longer response time.	Short response time.
Capital intensive.	Labor intensive.

The Role of Manufacturing and Service Operations in the Organization and Supply Chain

Operations management plays a critical role in the organization and supply chain. Without OM there would be no products to sell. However, operations cannot work in isolation from other business functions. Recall that each business function manages unique aspects of the business, and they all must work together. For example, operations must work with marketing to understand the exact wants of a particular group of customers. It can then design the exact products customers want and create the production processes to efficiently produce these products. Marketing, on the other hand, must understand operations' capabilities, including the types of products it can produce and the limitations of the production process. Without communication between marketing and operations, the company may find itself in a situation where it is producing products the customers don't want.

Operations must also work closely with purchasing to understand availability of materials, cost and quality issues, availability of sources of supply, and lead times. Operations links marketing—with its ties to customers—to sourcing—with links to sources of supply. Operations must understand exactly what customers want and be able to ensure that sourcing can get the materials needed at the right price and at the right time to support product designs, or offer alternative material options.

Ensuring that OM fits in with the other organizational functions is necessary but not sufficient. The reason is that each company depends on other members of its supply chain to be able to deliver the right products to its customers in a timely and cost-effective manner. In the upstream part of a company's supply chain, a company depends on its suppliers for the delivery of raw materials and components in time to meet production needs. If deliveries of these materials are late, or are of poor quality, production will be delayed, regardless of how efficient a company's operations process is. On the downstream side, a company depends on its distributors and retailers for the delivery of the product to the final customer. If these are not delivered on time, are damaged in the transportation process, or are poorly displayed at the retail location, sales will suffer. Also, if the operations function of other members of the supply chain is not managed properly, excess costs will result, which will be passed down to other members of the supply chain in the form of higher prices.

The bottom line is that companies that comprise a supply chain need to coordinate and link their operations functions so that the entire chain is operating in a seamless and efficient manner. Just consider the fact that most of the components Dell uses are warehoused within a 15-minute radius of its assembly plant, and Dell is in constant communications with its suppliers. Dell considers this to be essential to produce and deliver components in a timely fashion.

Organizational Decision Levels

Generally there are two levels of decisions in an organization. The first are *strategic decisions*. These decisions are broad in scope and long-term in nature. As a result they set the direction for the entire company. The second are *tactical decisions*, which are narrow in scope and short-term in nature. These two sets of decisions are intertwined with strategic decisions being made first and determining the direction of tactical decisions, which are made more frequently and routinely. Therefore, we have to start with strategic decisions and then move on to tactical decisions. This relationship is shown in Figure 1-3.

Strategic decisions set the tone for the other more specific decisions. They ask questions such as: What market are we in (and not in)? What are our unique strengths? How do we compete (and not compete)? These decisions are important as they define exactly how a company competes in the marketplace and exactly in what markets using specific strengths.

Tactical decisions focus on more specific day-to-day issues, such as the quantities and timing of specific resources, and how specific resources are used. They are bound by strategic decisions. Tactical decisions must be aligned with strategic decisions because they are the key to the company's effectiveness in the long run. Tactical decisions provide feedback to strategic decisions, which can be modified accordingly. Without the direction provided by strategic decisions, companies may pursue competition in areas that do not directly contribute to the business plan and waste resources. Consider for example a company such as Southwest Airlines, which has always had a clear strategic direction to compete on cost. This has directly impacted tactical decisions, such as pursuing cost cutting efforts in operations in the form of no frills and one aircraft to minimize scheduling costs.

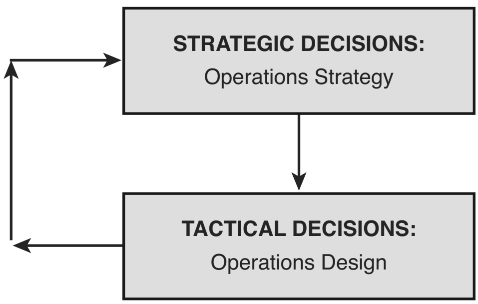

Figure 1-3 Levels of operations decisions

Key Terminology

Operations management requires making many strategic and tactical decisions. Here we look at some key operations management decisions and associated key terminology:

- **Capacity planning**—The process of determining the production capacity needed by an organization to meet changing demands for its products. Different types of capacity exist. For example, *design capacity* is the maximum amount of work that an organization is capable of completing in a given period; *effective capacity* is the maximum amount of work that an organization is capable of completing in a given period due to constraints such as quality problems, delays, and material management.
- **Efficiency**—Performing activities at the lowest possible cost.

- **Enterprise resource planning (ERP)**—Large, sophisticated software systems used for identifying and planning the enterprise-wide resources needed to coordinate all activities involved in producing and delivering products.
- **Forecasting**—The process of predicting future events, including product demand.
- **Just-in-time**—A philosophy designed to achieve high-volume production through elimination of waste and continuous improvement.
- **Lean systems**—Sometimes synonymous with just-in-time, it is a philosophy that takes a total system approach to creating efficient operations through the elimination of waste.
- **Location analysis**—Identifying the best location for facilities.
- **Mass customization**—The ability of a firm to highly customize its goods and services at high volumes through its operations management function.
- **Operations management (OM)**—The business function that refers to the transformation process of converting raw materials into finished goods and services; OM used to be called production and operations management (P&OM) or just production. As the field evolved from being primarily tactical (e.g., making inventory and scheduling decisions on the manufacturing floor) to being strategic (today there are many CEOs from the OM field), the term moved to focus on the broad notion of operations rather than mere production.
- **Product design**—The process of deciding on the unique and specific features of a product.
- **Process selection**—The process of identifying the unique features of the production process that will give the product its unique characteristics. Process selection typically goes hand in hand with product design, as we need to create a process that gives rise to the particular product design desired. An excellent product design is worthless if a process for its creation cannot be developed.
- **Productivity**—A measure of how efficiently an organization converts inputs into outputs. It is usually measured by a ratio of output divided by input. Productivity is essentially a scorecard of how efficiently resources are used and a measure of competitiveness. Productivity is measured on many organizational levels—from measuring labor and machine productivity to measuring the productivity of an entire organization or even a nation. As a result it is of interest to a wide range of people.
- **Quality management**—The process used to ensure the quality of a product, including measuring quality and identifying quality problems.

- **Reengineering**—The process of redesigning a company's processes to increase efficiency, improve quality, and reduce costs. In many companies things are done in a certain way that has been passed down over the years. Operations management is a key player in a company's reengineering efforts.
- **Scheduling**—The process of deciding on the timing and use of resources within an operation; it addresses questions such as who will work on what work schedule and in what sequence jobs will be processed.
- **Total quality management (TQM)**—A philosophy that seeks to improve quality by eliminating causes of product defects and by making quality the responsibility of everyone in the organization. With TQM everyone in the company is responsible for quality. Practiced by some companies in the 1980s, TQM became pervasive in the 1990s and is an area of operations management that no competitive company has been able to ignore.
- **Value added**—A term used to describe the net increase created during the transformation of inputs into outputs. The OM function seeks to create value added in the transformation process.

Critical Processes

Several critical processes drive the success of business operations. This section explains the most common ones.

Production Planning Processes

Production planning is an integral part of the business planning process. This process begins when management of an organization gathers input from the various organizational functions—such as finance, marketing, operations, and engineering—to develop a business plan. The business plan, with its long-term focus, provides the company's direction and objectives for the next two to ten years. The business plan is then typically updated and reevaluated annually. The business plan, which states the company's objectives for profitability, growth rate, and return on investment, is typically the starting point for the organization's production plan, often termed the aggregate plan. So what is a production plan?

The aggregate or production plan is an organizational plan that identifies the resources needed by operations management to support the business plan over the next 6 to 18 months. The aggregate plan details the aggregate production rate and the size of the workforce, which enables planners to determine the amount of inventory to be held; the amount of overtime or undertime authorized; any authorized subcontracting, hiring, or firing of employees; and back-ordering of customer orders. The production plan is usually updated and reevaluated monthly by operations management.

A company typically develops the production plan based on a composite product that represents the expected product mix. To minimize the level of details, individual products are not represented in the aggregate plan. Think about how many different products most companies have, and you can see that it would become cumbersome to include every product in the plan. Companies may group products into major product families to facilitate production planning. For example, a paint company may produce many different products, such as different colors of paint, different finishes (e.g., gloss versus flat), and container sizes (e.g., gallon or half gallon). Including all of these in a plan would be cumbersome. The aggregate plan considers a composite product—such as "gallons of paint" in this example—as a product measure.

The goal of the aggregate plan is to develop a plan for all the operations resources—machines, labor, and inventory—to produce the amount of product needed over a certain period of time. The aggregate plan will then specify for a particular period, say, the month of January, how many units of product are produced, how much labor is needed, and how much inventory. The goal is to have a big picture; using a composite product, or product families, reduces the level of detail but still provides the information needed for decision making. Common terms of output used in the aggregate plans are units, gallons, pounds, standard hours, and dollars. For example, a simplified production plan is shown in Table 1-2.

Table 1-2 A Simplified Production Plan

QUARTER	1	2	3	4
Demand	8,000	11,000	14,000	15,000
(Demand is given in units, say gallons or dollars.)				
Produce	12,000	12,000	12,000	12,000
(In this case we chose to produce average demand.)				
Inventory	4,000	5,000	3,000	0
(Inventory is computed as Amount Produced + Inventory from previous period – Demand.)				
Labor	6 workers	6 workers	6 workers	6 workers
(We assumed that each worker produces 2,000 units per quarter.)				

To summarize, the purpose of the production or aggregate plan is to develop production rates and authorize resources that allow the company to meet the objectives of the strategic business plan.

Master Production Schedule (MPS)

The plan below the production plan is a master production schedule (MPS). An MPS is the anticipated production schedule for the company expressed in specific configurations, quantities, and dates. It is stated as specific finished goods. It details how operations will use available resources and which units or models will be built in each time frame. This allows marketing to make informed commitments to customers. The MPS and the detailed sales plan are reviewed weekly or even daily.

The MPS is used as an anticipated schedule for building specific finished products and providing specific services. The key distinction here is that the MPS is a statement of production or services and is not a statement of demand—a plan to satisfy customer demand while considering operational effectiveness and cost. Due to this, individual products can be finished ahead of time and held in inventory rather than finished as needed. The master scheduler or office manager balances customer service and capacity usage.

The aggregate plan shows how many products or services are planned for each time period. The MPS identifies the specific products or services planned for a given period. The relationship of these plans is shown in Figure 1-4.

Material Requirements Planning (MRP)

The authorized MPS is a critical input into material requirements planning (MRP), the next plan below the MPS. MRP is a plan that uses the MPS, bill of material data, and inventory records to calculate specific requirements for materials. The MPS tells the MRP system what the company plans to build and when. The MRP system then calculates the materials needed to build the products in the schedule and plan for the necessary materials. Notice that as we move from the business plan through the production plan, MPS, and then MRP we progressively become more specific and detailed.

Rough Cut Capacity Planning (RCCP)

This is the process of converting the MPS into specific capacity requirements for key resources such as direct labor and machine time. This process calculates a rough estimate of the workload placed on critical resources by the proposed MPS. This workload is compared against demonstrated capacity for each critical resource. This comparison enables the master scheduler to develop a feasible MPS.

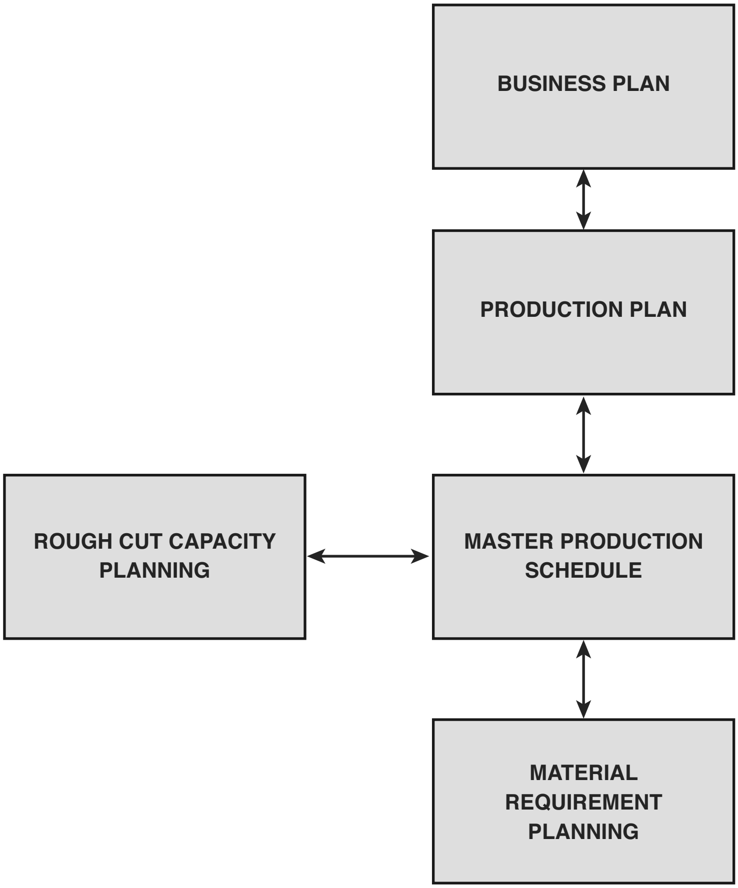

Figure 1-4 The relationships of different planning processes

Measuring Productivity Levels

Recall that operations management is responsible for managing the transformation of numerous inputs into a range of outputs, such as goods or services. But how do we know whether this transformation process is efficient? A measure of how efficiently inputs are converted into outputs is called *productivity*. Productivity measures how well resources are used. It is computed as a ratio of outputs (goods and services) to inputs (labor and materials). The more productive a company is, the better it uses its resources. The equation is as follows:

Productivity = output/input

This measure of productivity can be used to measure the productivity of one worker or many, as well as the productivity of a machine, a department, the whole firm, or even a nation. *Total productivity* is used when measuring productivity for all inputs combined, such as labor, machines, and capital. For example, let's say a company produces weekly the equivalent of $10,000 in output in the form of finished goods. Let's also say that the weekly value of all the inputs combined—including labor, materials, and other costs—is $5,000. Total productivity for the week for the company is

Total Productivity = output/input = $10,000/$5,000 = 2.0

Although total productivity is valuable to give a company a sense of how it is doing on the whole, it is often much more useful to measure the productivity of one variable at a time. This allows us to evaluate how efficiently various resources are being used. *Partial productivity* or *single-factor productivity* is when we compute productivity as the ratio of output relative to a single input. For example, we can compute machine productivity or labor productivity. For machine productivity we can see how many units a machine is processing over a certain period of time; similarly for labor productivity we can compute how many units a worker can process over a certain period of time, such as a day, hour, or month.

The interpretation of productivity is not as easy as you might think. Productivity is a relative measure that should be tracked over time. This allows us to benchmark against ourselves, our competitors, and our industry. Just looking at the number, such as the 2.0 in the previous computation of total productivity, does not reveal much. Consider, for example, if one worker at a sub shop produced 20 subs in 2 hours, the productivity of that worker is 10 subs per hour. This number by itself does not tell us much. However, if we compare it to the productivity of two other workers, one who produces 8 per hour and another 5 per hour, it is much more meaningful. Although this is a simplistic example, it illustrates the point that performance expectations are relative, and they need to be benchmarked and compared over time. By comparing our productivity over time and against similar operations, we have a much better sense of how high our productivity really is.

Another criterion for evaluating productivity and setting standards for performance is considering the company's strategy for competing in the marketplace. This is called a *competitive priority*, and it defines how a company competes. A company that competes based on speed would probably measure productivity in units produced over time. However, a company that competes based on cost might measure productivity in terms of costs of inputs such as labor, materials, and overhead. On the other hand, a company that competes on quality may measure productivity based on the number of errors made. The important thing is that the productivity measure selected provides information on how the company is doing relative to the competitive priority it defines as most important.

Inventory Determination

Inventory is quantities of goods in stock. This is true for any product, material, or good. Consider the books or CDs on your bookshelf. They comprise an inventory of books. They provide you with a certain value from enjoying them to the monetary value you paid for them. They cost money to purchase—money that cannot be used for something else. The same is true for inventory companies hold in stock. When we talk about inventory we are simply talking about quantities of materials a company has in storage. This material serves many purposes, but it also ties up a great deal of funds. As a result, managing inventory throughout the entire supply chain is important.

All organizations—both manufacturing and service organizations—carry inventory. A great deal of inventory must be carried to support basic processes of the operation. In manufacturing, inventory can take a variety of forms. This includes raw materials and component parts, which are delivered from suppliers, work-in-process (WIP) inventory, or finished goods. Inventory also includes supplies and equipment. Inventory can tie up funds if it sits unutilized in stock; however, not having enough inventory when needed can mean stockouts or production delays. As a result managing inventory is a critical part of operations management.

The major decisions in inventory relate to when to replenish stock, and how large orders should be. This is called an *inventory policy*. An inventory policy addresses the basic questions of *when* and *how much* to order. To understand more about determining an inventory policy we need to first look at some reasons for carrying inventory.

Reasons for Carrying Inventory

Organizations carry inventory for many reasons, and all companies—even those that practice lean systems—carry inventory. In fact, organizations cannot run without a certain amount of inventory. Some reasons that organizations carry inventory are as follows:

1. **Protect against stockouts**—One reason for carrying inventory is that goods cannot arrive immediately when you run out of stock. A certain amount of lead time is needed for goods to be produced and delivered. You have to make sure that you have enough inventory in stock to cover demand during the period of lead time. Lead time will have a certain amount of variation, which may result from shipping delays, production problems at the supplier site, lost orders, defective materials, and numerous other problems so you have to plan to be prepared. Also, sources of supply are rarely at the same location as demand, and you cannot locate a production facility everywhere there is demand. As a result, inventory has to be transported from one location to another, and sometimes held in a distribution center to be distributed when needed at the various locations. The result is the need to carry inventory to protect against possible stockouts.

2. **Maintain independence of operations**—During the production process as well as the supply chain, the product is moved through many different operations that have different processing rates. The challenge is balancing different processing capabilities, and it is not always possible. Therefore, you need a cushion between operations, and inventory at different points in the system serves this purpose. Extra inventory strategically placed evens out differences in processing capability. Extra stores of inventory can be placed at various points in the supply chain network, or at work centers within a facility, to give it flexibility.

   Just consider the high interdependence of work stations on an assembly line. Inventory is typically placed between work stations to decrease their interdependence. Otherwise, work stoppage at one station may disrupt or otherwise shut down the entire assembly line. Also consider that there is natural variation in processing times between identical operations due to randomness. As a result it is desirable to create a cushion of inventory so that output can occur at a constant rate.

3. **Balance supply and demand**—Balancing supply on one side of the supply chain with demand on the other is always a challenge. Demand is never known with certainty and holding extra inventory enables an organization to meet unexpected surges in demand. Also, consider that demand occurs intermittently, rather than on a continuous basis. An example might be retail sales, which are slower on weekday mornings but high over the weekends. Not having extra inventory might mean missed sales. Carrying inventory helps to address these natural variations in demand.

   Seasonal demand patterns also contribute to high and low periods of demand, such as ice cream sales in the summer or snow shovel sales in the winter. It would be costly for production facilities to produce products in unison with the seasonality of demand. This might mean closed facilities and unemployed workers during low seasons, and overtime production during high seasons. A more common strategy is for companies, and their supply chains, to produce at a more uniform rate during the year. In this case extra products are stored in inventory and used during peak seasons.

4. **Protect against uncertainty**—Many unexpected events occur that impact both supply and demand. This is due to randomness and could be anything from a batch of damaged goods being received, to an unexpected delay due to weather, or a strike at a supplier's plant. Companies carry extra inventory in stock to protect themselves, or buffer, against these uncertainties. This is a "just in case" scenario. However, companies know that they have to be prepared so that they don't run out of stock.

5. **Economic purchase orders**—You have heard about keeping inventories low, but in this scenario inventory may be purchased in large quantities. There are a number of reasons why this might be advantageous. For example, suppliers sometimes offer price discounts to encourage customers to purchase larger quantities at one time. Similarly, buying in large quantities might result in savings associated with transporting larger quantities at one time. Also, anticipating some type of price increase, shortage, or disruption might lead companies to buy larger quantities. Purchasing larger quantities in anticipation of shortages, for example, is a common supply chain strategy.

Types of Inventory

To better understand inventory we need to look at different types of inventories and their purposes, as their quantities are computed differently. Together they collectively add up to inventory costs for the organization. Let's look at these here:

- **Cycle stock**—This category of inventory is computed for immediate use and is also called lot size inventory. It is computed based on expected demand over a certain time period and assumes demand is known. This simply computes how much stock is needed to cover demand over a set period of time. It also accounts for the fact that products are typically produced in batches. This is the quantity, or the size, of the batch that is produced during the production cycle. Therefore it is called *cycle stock*.
- **Safety stock**—This is inventory carried to serve as a cushion for uncertainties in supply and demand. It can be in the form of finished goods to cover unexpected demand, raw materials to guard against supply problems, or work-in-process inventories to guard against production stoppages.
- **Seasonal inventory**—These inventories are carried to compensate for differences in the timing of supply and demand, and to smooth out the flow of products throughout the supply chain. They are called seasonal inventories as they are often used when demand fluctuations are significant, but predictable, such as with seasonal variation. This is where companies carry extra inventory during a low season in anticipation of higher demands during the high season. Finally, these are inventories that are carried in anticipation of a price increase or a shortage or products. For this reason they are sometimes called hedge inventory.
- **Transportation or pipeline inventory**—This is inventory that is in transit and exists merely because the points of demand and supply are not same. At any one time a global supply network has a large percentage of its inventory in transit—on a barge, truck, or rail—being moved from one location to another, or waiting to be loaded or unloaded.

- **Maintenance, repair, and operating (MRO) items**—In addition to inventories that directly support product creation, other inventories are used indirectly. These are MRO items and include everything from office supplies and forms, to toilet paper and cleaning supplies, to tools and parts needed to repair machines. Collectively, MRO items make up a significant amount of inventory and need to be managed like all other inventories. Just think about the amount of paper, pencils, and other supplies in an office. You expect them to be there, and without them work can be significantly hampered.

Inventory Policy Choices

As discussed earlier an organization's inventory policy must answer the two basic questions: *when to order* and *how much to order*. There are two basic categories or choices in inventory policy that accomplish this: fixed-order quantity systems and fixed-time period systems. They work in slightly different ways. Let's look at these now.

Fixed-Order Quantity System

The first policy choice is through a system called a *fixed-order quantity system*. Therefore, two variables define this system and answer the two basic questions of when to order and how much. The first is an order quantity, Q, and the second is a reorder point, ROP. As the name suggests, the quantity ordered with this system is constant or fixed and is denoted by Q. An order is placed when the inventory position drops to some predetermined level. This predetermined level is called the reorder point and is usually noted as ROP. Together these variables specify when to place an order: *when inventory reaches the ROP.* They also specify how much to order: *the quantity Q.*

A graphical presentation of this model is shown in Figure 1-5. Notice that the system assumes a constant demand rate of *d* by which the inventory position (IP) is reduced. When the IP reaches the ROP, an order is placed for the quantity Q. When goods arrive, the inventory is replenished, and all at once the inventory position is increased by Q. However, inventory cannot arrive the moment an order is placed as there is a certain amount of lead time, L, during which we have to wait for the order.

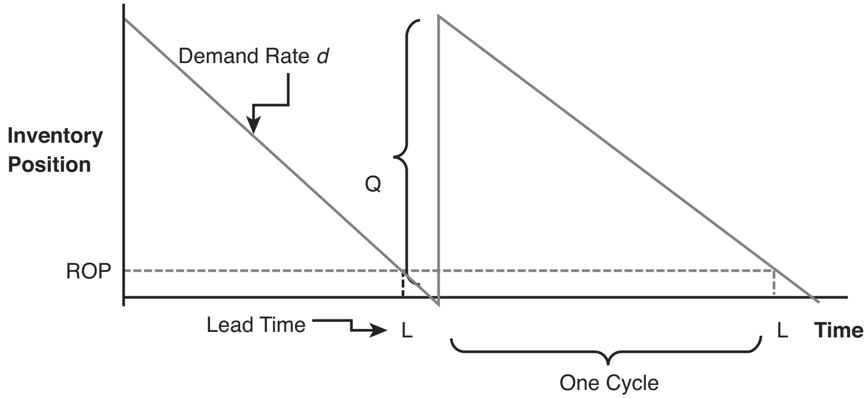

Figure 1-5 Fixed-order quantity system

Here inventory is monitored on a continual basis, and the assumption is that we always know the current level of inventory. When inventory levels reach the ROP, an order of quantity Q is placed. For example, let's assume that a grocer uses a fixed-order quantity system for its inventory of canned tomato soup. Its policy may be that it always orders 200 cans of soup, for which it gets a nice quantity discount, and the order is made when the number of cans of soup drops to 25. Therefore, the ROP = 25, and the Q = 200.

In the classic version of this system Q is computed as the economic order quantity (EOQ)—an economically optimal order quantity—which we will compute later. For this reason this system is sometimes called the *economic order quantity (EOQ) model*. Other terms used to describe it are the *Q-model* as the quantity Q is constant. Sometimes it is called a *continuous review system*, as the inventory levels are continuously monitored. The model has even been called a *sawtooth model*, as the graph of inventory looks like a sawtooth. All these terms refer to the same type of inventory system, describing different features of the system itself.

Fixed-Time Period System

The second inventory policy is determined by a system called a *fixed-time period system* shown in Figure 1-6. This system checks inventory levels in fixed time intervals labeled as T. The result is that the quantity ordered varies based upon the inventory position when the system is checked. The system sets a target inventory level it wants to maintain, say R. Inventory is checked every T intervals, say every week or every two weeks, and an order is placed to restore the inventory level back to R. Based on the inventory level at time period T, the amount of inventory that needs to be ordered will be some quantity Q that varies from period to period. This quantity Q is the difference between the target inventory R and how much inventory is in stock—the IP at time T:

Q = R – IP

where:

Q = order quantity

R = target inventory level

IP = inventory position

Two variables define this system and answer the two basic questions of when to order and how much: T and Q. They specify when to place an order: *at time interval T.* They also specify how much to order: *quantity Q, computed as the difference between the target inventory, R, and the inventory position, IP.* Sometimes this system is called the *periodic review system* to indicate that the inventory level is checked periodically, rather than continuously.

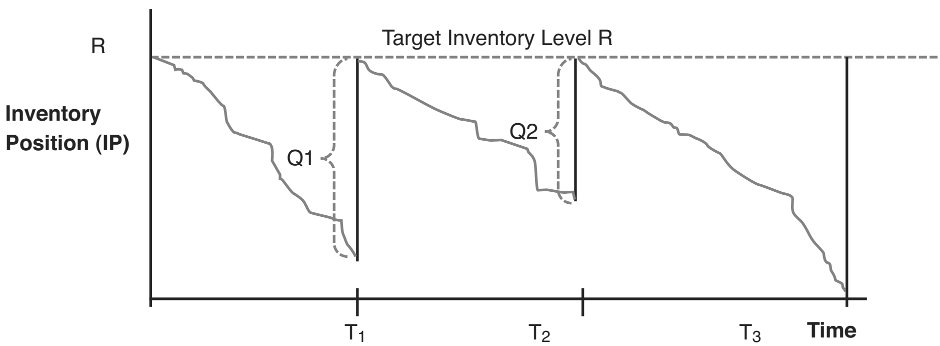

Figure 1-6 Fixed-time period system

We can assume that an auto manufacturer uses a fixed-time period mode for its inventory of alternators. Also, let's say its policy is to check inventory levels every two weeks, and that it has a target inventory level R = 5,000 alternators. If after two weeks the company checks its inventory level and finds its inventory position IP = 2,800 alternators, it would place an order for quantity Q = R – IP = 5,000 – 2,800 = 2,200 alternators. This is essentially how this policy system works.

The biggest difference between the fixed-order quantity system and the fixed-time period systems is in the timing and quantities of the orders placed. With the fixed-order quantity system inventory is checked on a continual basis and the system is prepared to place orders multiple times per year on a random basis. This has an advantage of providing greater system responsiveness, but it also requires administrative processes to be in place on a continual basis. In addition, as different inventory items reach their reorder points at different time periods, it might be difficult to obtain quantity discounts based on a bundled order.

The fixed-period order system requires carrying more safety stock inventory. The reason is that with this system we do not check the IP on a regular basis, and a sudden surge of demand could lead to a stockout. This system, however, allows more organized purchasing as inventory levels are checked in set time intervals. Orders can be bundled and quantity discounts obtained more easily, which can provide an advantage. In a fixed-order quantity system different items may reach reorder points at different times generating many orders at random intervals. On the other hand, a fixed-period system could ensure that inventory levels are checked on a regular basis for all items—say every two weeks. Then the orders for all the items could be bundled.

Inventory Policy in a Fixed-Order Quantity System

A fixed-order quantity system is one of the most important in inventory management. For that reason we need to look at how to compute the two variables that define it: the order quantity Q and the reorder point ROP. Before we do that, however, we need to look at the assumptions this system makes. Most importantly, the system assumes that all the variables occur at a constant rate and their values are known with certainty. For example, the system assumes that the demand, D, occurs at a constant rate and that there is no variability in demand. Also, the lead time, L, is constant, the holding cost, H, is known and fixed, as are stockout cost, S, and unit price, C. Although these assumptions are not realistic the model is highly robust and provides excellent results despite these assumptions.

How Much to Order?

The first decision in the fixed-order quantity model is to select the order quantity Q. Recall that there are a number of inventory costs, most notably inventory holding cost and ordering cost. We want to select the "best" order quantity that minimizes these costs—the EOQ mentioned previously. This is computed by looking at the total annual inventory cost and finding the order quantity that minimizes it. Consider that the total annual cost is comprised of annual purchase cost, annual ordering cost, and annual holding cost, and looks as follows:

Total cost = Purchase cost + Ordering cost + Holding cost

$$TC = DC + (D/Q)\,S + (Q/2)\,H$$

where

TC = Total cost

D = Annual demand

C = Unit cost

Q = Order quantity

S = Ordering cost

H = Holding cost

The first term in the equation, DC, is the annual purchase cost for items. It is comprised of annual demand (D) times the unit cost of each item (C). The second term (D/Q) S is the annual ordering cost. It is computed as the number of orders placed per year (D/Q), times the cost of each order, S. Finally, the third term is annual holding cost where (Q/2) is the average inventory held. Remember that our maximum inventory is Q units when the order is received. When inventory is depleted we have zero. Therefore on average we have Q/2 units in inventory. H is the annual holding cost per unit of inventory.

The behavior of the two costs is shown in Figure 1-7. Notice that inventory holding cost increases with the order quantity, Q. The reason is that higher order quantities mean holding more inventory. However, this also means that we are ordering less frequently so ordering cost decreases. The opposite is true as the order quantity Q is decreased. A smaller order quantity results in a lower holding cost, but a higher ordering cost, as we are ordering more frequently.

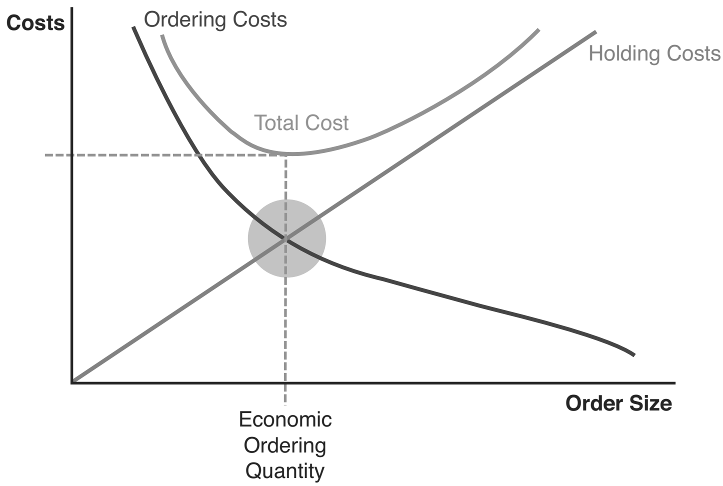

Figure 1-7 Ordering versus holding cost

The objective is to pick an order quantity that minimizes the sum of both the holding and ordering costs, which is the minimum point on the total cost curve. To compute this we use calculus and end up with the following classic computation of the "best" or optimal order quantity, the EOQ:

$$\text{EOQ} = \sqrt[2]{2DS/H}$$

When to Order?

The EOQ answers the question of how much to order, but we still need to determine when to order. Assume that the demand rate (D) and lead time (L) are constant and known with certainty. In that case the ROP would simply be enough inventory to ensure that demand is covered during the length of the lead time. In this simple case, the ROP would be computed as

ROP = demand during lead time

ROP = D L

Let's assume that lead time L for a product is one week and the demand, *d*, is 250 units per week. The ROP would be

Reorder Point = ROP = D x L = 1 week x 250 = 250 units

This means that every time inventory reaches 250 units an order is placed for the economic order quantity Q.

Unfortunately, D and L are rarely fixed, and demand is often higher than expected. As a result we often have to carry a bit more inventory to address this uncertainty. This is called *safety stock* or *buffer stock* and is inventory we carry in addition to the demand during lead time. Safety stock is added to the ROP calculation and is computed as follows:

ROP = demand during lead time + safety stock

ROP = D L + SS

Safety stock is computed based on the service level a company wants to maintain, which is simply the chance that we will *not* run out of stock. This is set by the company based on the level of service it wants to provide for a particular product and customer base. Higher service levels mean higher levels of inventory. Another factor that is used to compute safety stock is the variability of demand. The higher the variability and the higher the service level the higher the safety stock, or the amount added to the final computation of the ROP.

Independent Versus Dependent Demand

Another way to understand inventory is to separate it into two broad categories: dependent and independent demand. Understanding this difference is important as the entire inventory policy for an item is based on this. Independent demand is *demand for a finished product*, such as a computer, a bicycle, or a pizza. Dependent demand, on the other hand, is *demand for component parts or subassemblies*. For example, this would be the microchips in the computer, the wheels on the bicycle, or the cheese on the pizza.

The two inventory systems we discussed are used to determine order quantities for independent demand. But how do we compute quantities for dependent demand? Quantities for dependent demand are *derived* from independent demand, which we call the "parent." For example, we can forecast the amount of automobiles we expect to sell, then we can derive the quantities needed of wheels, tires, braking systems, and other component parts. For example, if a company plans to produce 200 cars in a day, it would need 800 wheels, 400 windshield wipers, and 200 braking systems. The number of wheels, windshield wipers, braking systems, and other component parts is dependent upon the quantity of the independent demand item from which it is derived.

The relationship between independent and dependent demand is depicted in a *bill of materials (BOM)*, a type of visual diagram that shows the relationship between quantities. An example is shown in Figure 1-8. Item A is the independent demand item. All the other items are dependent demand. The quantities that go into the final item are shown in parentheses. Notice that two units of C are combined with one unit of B to make the final product. Similarly, two units of D and one unit of E are combined to make one unit of B.

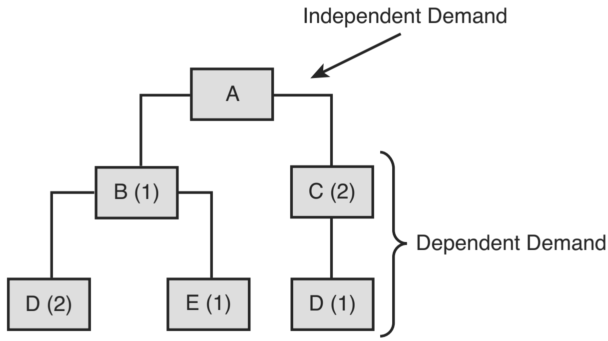

Figure 1-8 A bill of materials (BOM)

Dependent demand order quantities are computed using a system called *material requirements planning (MRP)*, which considers not only the quantities of each of the component parts needed, but also the lead times needed to produce and receive the items. For example, 20 units of A means that 20 units of B are needed, as are 40 units of C; similarly, 40 units of D and 20 units of E are needed. However, the system must also take into account differences in lead times, as receiving D may have a different lead time than receiving E. This means that the orders should be placed at different times. This system can also be tied to costs of goods and can link internal and external members of the supply chain.

ABC Inventory Classification

An important aspect of managing inventory is to have a way to classify it based on its importance. All items in the supply chain are not of equal importance. Some are very important, such as specialized surgical equipment. Others are less important, such as latex gloves in a hospital. The first step in managing inventory is to classify inventory based on its degree of importance to manage it properly. The tool for this is ABC classification. Classifying inventory based on degree of importance allows us to give priority to important inventory items and manage those with care. It also prevents us from wasting precious resources on managing items that are of less importance.

ABC classification is based on Pareto's Law, which states that a small percentage of items accounts for a large percentage of value. This value can be sales, profits, or other measure of importance. Roughly 10 percent to 20 percent of inventory items account for 70 percent to 80 percent of inventory value. These highly valuable items are classified as A inventory items. Moderate value items account for approximately 30 percent of inventory items and contribute to roughly 35 percent of the total. They are called B items. Finally, approximately 50 percent of the items only contribute to roughly 10 percent of total inventory value. These are called C items and are of least importance. Figure 1-9 provides an example of ABC analysis.

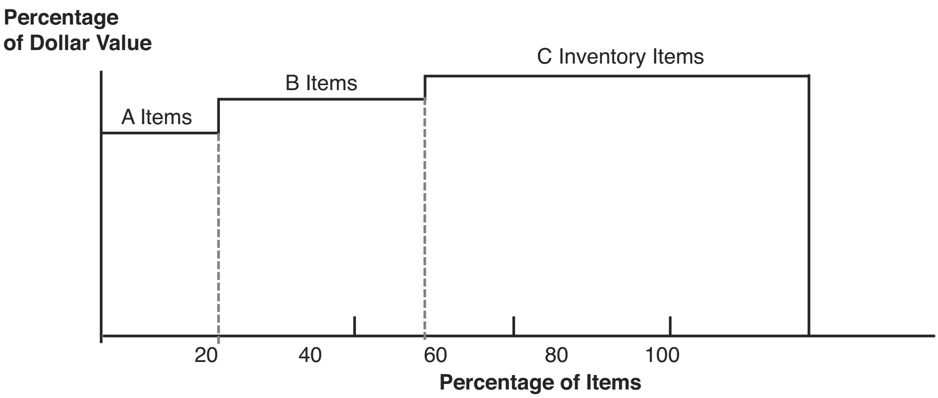

Figure 1-9 ABC classification of inventory

The steps to conduct an ABC analysis are as follows:

1. Determine annual usage or sales for each item.
2. Determine the percentage of the total usage or sales by item.
3. Rank the items from highest to lowest percentage.
4. Classify the items into groups.

After ranking the items from highest to lowest percentage, do not force groups to fit the preset percentages, as these are rough estimates. Rather, there are typically natural breaking points that will occur. The data will naturally group itself and these are groupings that should be used.

ABC analysis is extremely important for determining order policies. The most sophisticated inventory systems should be used for A items. In fact, many managers personally oversee these. By contrast, C items are typically left for automated ordering systems as they do not warrant the cost of managerial involvement.

Vendor Managed Inventory (VMI)

A unique yet important aspect of managing inventory considers who owns it. Historically companies owned and managed all of their inventories. They were responsible for the storing, controlling, replenishing, and overall management of the inventory. With supply chain management (SCM), most of this has changed. Today, many firms have implemented vendor management inventory (VMI) arrangements. Here, the vendor is responsible for managing the inventory located at a customer's facility. The vendor stocks the inventory, places replenishment orders, and arranges its display. The vendor typically owns the inventory until it is purchased by the customer.

VMI offers a number of important advantages to both the customer and the vendor. The vendor has greater control over its product. The vendor is required to work much more closely with the customer, giving the vendor a better understanding of how to serve the market. The customer, in turn, has less responsibility and financial burden over the inventory items. VMI requires both the vendor and the customer to work closely together. It represents one of the many partnership arrangements that have evolved in supply chain management.

Challenges Facing the Modern Operations Manager

Despite all the tools and systems at their disposal, operations managers face extensive challenges when it comes to managing an organization's resources. The global marketplace is characterized by its substantial size and dynamic makeup. The operations manager must grasp this reality to maintain optimal process performance in a shifting global landscape. Successful operations managers stay abreast of these trends and implement proactive systems to take advantage of them. Globalization, technology advancements, and redefined marketplace priorities are among the many challenges at hand today.

Globalization has radically altered the way operations managers conduct their day-to-day activities. Landforms, distances, and time zones no longer separate people from information. Because of this, modern corporations can—and, in some competitive instances, must—base their operations in any number of countries to minimize costs and maximize performance efficiency. Consider Toyota, an automobile company headquartered in Tokyo, Japan. Toyota has made significant investments in American operations. Even though companies such as Ford and GM pride themselves on domestic manufacturing, Toyota's popular Avalon model is actually considered one of the most "American-made" cars. Assembled in Kentucky, the Avalon contains nearly 85 percent North American parts.[1] Globalization turned Toyota and other foreign automakers into giants in the United States—and nearly put American automakers out of business.

The instantaneous availability of information is directly attributable to modern technological advancements. As you will see in subsequent chapters, technologies such as global positioning systems (GPS) and radio-frequency identification (RFID) have revolutionized inventory management. Corporations can now account for inventory in real time, no matter how dispersed it is. What's more, these technological advancements have made planning systems more precise, thereby narrowing operations managers' margins for error. Technology is moving at breakneck speed. Keeping up can be rewarding, but failing to do so can be catastrophic.

The global marketplace has been, and is continuing to be, redefined by new priorities. With a growing population depending on a fixed amount of resources, companies are being forced to make sustainability a priority. There is no better example of corporate sustainability than at search engine giant Google. Google is famous for making use of renewable energy resources. Instead of lawn mowers, it invites goats to trim the grass of its green areas. Customer priorities are changing, too, especially when it comes to health. Because of social and political pressure, fast food companies such as McDonalds have introduced fruit to their children's menus. Burger King recently released a new version of its French fries. Known as "Satisfries," these French fries have 30% fewer calories than Burger King's traditional fries. Changes such as these are impacting the ways businesses must conduct operations management and will continue to create operational challenges. The companies with the most savvy operations managers will be able to embrace the adversity challenges present and change the marketplace in the process.

Discussion Questions

1. What are some characteristics of operations management that make it a core business function?
2. Explain the "transformation role" of operations management.
3. Differentiate between the two categories of organizations.
4. Cite examples of how operations management works in tandem with other business functions. How can poor operations management affect the entire supply chain?
5. Define *strategic decisions* and *tactical decisions*. Which type of decision should an organization make first? Why is it important to start with one before the other?
6. What is the difference between *productivity* and *efficiency*?
7. What is the purpose of the production—or aggregate—plan?
8. Detail the relationships among the critical planning processes.

9. How should productivity be measured? Should all organizations/industries measure productivity the same way? Why or why not?
10. How can carrying inventory protect against stockouts, balance supply/demand, and protect against uncertainty? What are the consequences of not carrying inventory?
11. Explain how each inventory management system determines its order timing and its order quantity.
12. How does the Pareto Law assist in ABC classification?
13. VMI offers a vendor greater control over its products. How does VMI also help the customer?

Endnote

1. http://editorial.autos.msn.com/what-are-the-most-american-made-automobiles#2.

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