INTRODUCTION TO OPERATIONS MANAGEMENT (NWTC)

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Introduction to Operations Management (NWTC)

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This text was compiled on 05/08/2026

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Detailed Licensing

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Acknowledgements

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This adaptation was sponsored by Seneca's Open Text Adaptation Grant Program. Resources and support were also provided by the Teaching & Learning Centre at Seneca.

CHAPTER OVERVIEW

1: Introduction to Operations Management

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Learning Objectives

- What is Operations Management?
- Describe the transformation process and some categories.
- Why should a business student study Operations Management?
- What are some of the Professional Organizations involved in Operations Management?
- Describe each of the three phases of Operations Management history.
- Discuss how producing goods is different from performing services.

Operations management is a vast topic but can be bundled into a few distinct categories, each of which will be covered in later units. (It should be noted that entire courses could be devoted to each of these topics individually). Since most people do not work in a formal operations department, we will begin with an overview of operations management itself.

The top manager of an operations department is usually called the **Director of Operations**.

Most operations departments will report to a **Chief Operating Officer** (COO), who reports to the **Chief Executive Officer** (CEO).

The COO is often considered the most important figure in a firm, next to the CEO.

The history of operations management can be traced back to the industrial revolution when production began to shift from small, local companies to large-scale production firms. One of the most significant contributions to operations management came in the early 20th century when Henry Ford pioneered the assembly line manufacturing process. This process drastically improved productivity and made automobiles affordable to the masses. Understanding the motivations behind innovations of the past can help us identify factors that may motivate individuals in the future of operations management.

1.1: What is Operations Management?
1.2: Transformation Process
1.3: The Operations Function
1.4: Why should I study Operations Management?
1.5: Development of Operations Management
1.6: Producing Goods and Services
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1.1: What is Operations Management?

Operations management is the management of the processes that transform inputs into the goods and services that add value for the customer. Consider the ingredients of your breakfast this morning. Unless you live on a farm and produced them yourself, they passed through a number of different processing steps between the farmer and your table and were handled by several different organizations.

Every day, you use a multitude of physical objects and a variety of services. Most of the physical objects have been manufactured and most of the services have been provided by people in organizations. Just as fish are said to be unaware of the water that surrounds them, most of us give little thought to the organizational processes that produce these goods and services for our use. The study of operations deals with how the goods and services that you buy and consume every day are produced.

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1.2: Transformation Process

A **transformation process** is any activity or group of activities that takes one or more inputs, transforms and adds value to them, and provides outputs for customers or clients. Where the inputs are raw materials, it is relatively easy to identify the transformation involved, such as when milk is transformed into cheese or butter. Where the inputs are information or people, the nature of the transformation may be less obvious. For example, a hospital transforms ill patients (the input) into healthy patients (the output).

Examples of Transformation Processes

- Changes in the physical characteristics of materials or customers
- Changes in the location of materials, information or customers
- Changes in the ownership of materials or information
- Storage or accommodation of materials, information or customers
- Changes in the purpose or form of information
- Changes in the physiological or psychological state of customers

Often all three types of **input** – materials, information and customers – must be transformed by a single organization. For example, withdrawing money from a bank account involves information about the customer's account, materials (such as checks and currency), and the customer. Treating a patient in hospital involves not only the "customer's" state of health, but also any materials used in treatment and information about the patient.

As Figure 1.2.1 demonstrates, transformation processes can be categorized into four groups: manufacture (the physical creation of products, e.g. automobiles), service (the treatment of customers or storage of products, e.g. hospitals or warehouses), supply (a change in ownership of goods, e.g. retail), and transport (the movement of materials or customers, e.g. taxi service).

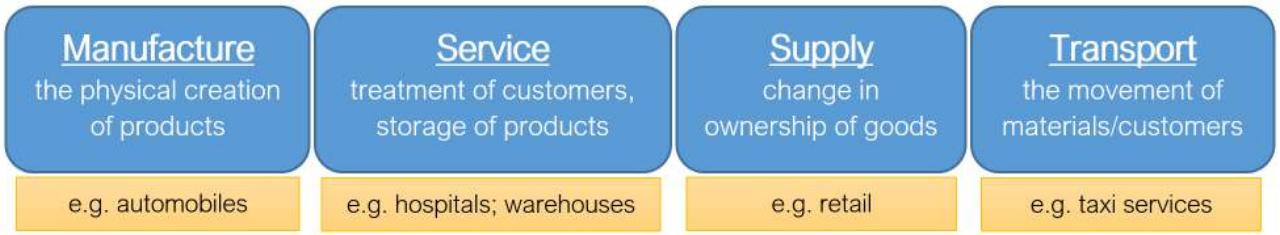

Figure 1.2.1: Categories of transformation processes.

Several different transformations are usually required to produce a good or service. The overall transformation can be described as the **macro operation**, and the more detailed transformations within this macro operation as **micro operations**. For example, the macro operation in a brewery is making beer (Figure 1.2.2). The micro operations include:

- milling the malted barley into grist
- mixing the grist with hot water to form wort
- cooling the wort and transferring it to the fermentation vessel
- adding yeast to the wort and fermenting the liquid into beer
- filtering the beer to remove the spent yeast
- decanting the beer into casks or bottles.

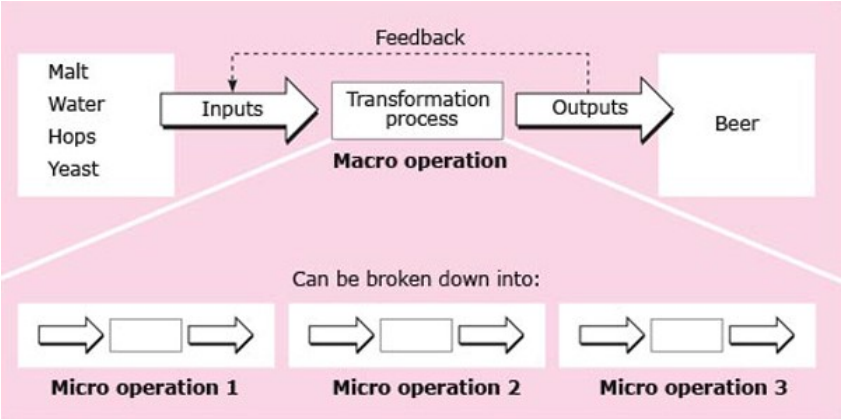

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Figure 1.2.2: Macro and micro operations (transformation processes); Credit: The Open University / open.ed

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1.3: The Operations Function

Every organization has an operations function, whether or not it is called ‘operations’. The goal or purpose of most organizations involves the production of goods and/or services. To do this, they have to procure resources, convert them into outputs and distribute them to their intended users. The term **operations** embraces all the activities required to create and deliver an organization’s goods or services to its customers or clients.

Within large and complex organizations, operations is usually a major functional area, with people specifically designated to take responsibility for managing all or part of the organization’s operations processes. It is an important functional area because it plays a crucial role in determining how well an organization satisfies its customers. In the case of private-sector companies, the mission of the operations function is usually expressed in terms of profits, growth and competitiveness; in public and voluntary organizations, it is often expressed in terms of providing value for money.

Operations management is concerned with the design, management, and improvement of the systems that create the organization’s goods or services. The majority of most organizations’ financial and human resources are invested in the activities involved in making products or delivering services. Operations management is therefore critical to organizational success.

Other functions of the Business:

A typical organization has four distinct basic functional areas; operations, marketing and sales, finance, and human resources.

Operations is the area that is responsible for directly creating the product or service for which the customer will pay. The other three departments ensure that the operations area of the business has everything needed in order to do the work.

Marketing – ensures that operations is producing the right product or service in a way that provides customers with all the features or characteristics that they value.

Finance – ensures that the funds for materials, supplies, payroll and equipment are available when needed.

Human Resources – ensures that the correct employees, with the adequate skills and experience are recruited, hired and trained. They are responsible for compensation, collection of income taxes, administration of benefits, succession planning and more. Without HR, there would be no employees in the operations department.

Figure 1.3.1: Business functions of departments.

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1.4: Why should I study Operations Management?

In most organizations, operations tends to be the largest department in terms of the number of employees. For a new graduate, you may be smart to look for a position within the operations of a business. In a larger company these jobs are far more plentiful than those in smaller departments. If you have a passion for working for a large organization, you might want to focus more on which organization you go to work for, and less focus on the actual job title. Soon enough, if you're punctual, energetic and proactive, you will likely apply or get promoted into the job you desire.

Operations is where the largest share of the firm's dollars are spent. It is a huge focus of top management.

All other departments in the organization are interrelated with operations. In finance, marketing and human resources, you will be interacting with operations on a regular basis. You should understand the businesses' core transformation process regardless of the department in which you work.

Major innovations are made through operations. If you look at successful companies such as Toyota, Amazon, or Dell, you will find that the keys to their success came from innovations to the operations processes of their businesses.

Operational innovation means coming up with entirely new ways of filling orders, developing products, providing customer service, or doing any other activity that an enterprise performs.

As a new grad in an organization, you will find that every business is looking for new ideas, tools, and improvement suggestions in order to improve on the effectiveness and the efficiency of the business.

- **Effectiveness** refers to making the right actions and plans in order to improve the business and add value for the customer. It is helping to get the business doing the right things for the customer.
- **Efficiency** is different. To be efficient means doing things well at the lowest cost possible. To be efficient, we look for ways to reduce unnecessary or redundant activities that add unnecessary cost and could be avoided.

Often, decisions that must be made will involve a trade-off between effectiveness and efficiency. Consider the decision to hire an extra full time server in a restaurant. The service may be faster and customers will feel as though their server was more attentive to their table. However, this comes at a higher cost, which is a reduction in efficiency.

We think of value as the relationship between quality and price. If we can provide the customer with a better quality product at the same price point, then that is adding value. If we are able to provide the same product but at a lower price, then the customer wins again.

Resources for Operations Management learners and professionals:

- Supply Chain Management Association (SCMA) (opens in new window)
- Canadian Institute of Traffic and Transportation (CITT) (opens in new window)
- Association for Supply Chain Management (APICS) (opens in new window)
- American Society for Quality (ASQ) (opens in new window)
- Project Management Institute (PMI) (opens in new window)

? Activity:

Look at ONE of the Associations above and answer the following questions:

1. Is this organization Canadian, or multinational?
2. Is there an opportunity for students to join? If yes, is there a fee, and how much?
3. Are there opportunities for networking and to meet professionals?
4. Do they offer job search assistance?
5. Would you consider joining either of these organizations? Why or why not?

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1.5: Development of Operations Management

Operations in some form have been around as long as human endeavor itself but, in manufacturing at least, it has changed dramatically over time, and there are three major phases – craft manufacturing, mass production and the modern period. Let's look at each of these briefly in turn.

Craft manufacturing

Craft manufacturing describes the process by which skilled craftspeople produce goods in low volume, with a high degree of variety, to meet the requirements of their individual customers. Over the centuries, skills have been transmitted from masters to apprentices and journeymen, and controlled by guilds. Craftspeople usually worked at home or in small workshops. Such a system worked well for small-scale local production, with low levels of competition. Some industries, such as furniture manufacture and clock-making, still include a significant proportion of craft working.

Mass production

In many industries, craft manufacturing began to be replaced by **mass production** in the 19th century. Mass production involves producing goods in high volume with low variety – the opposite of craft manufacturing. Customers are expected to buy what is supplied, rather than goods made to their own specifications. Producers concentrated on keeping costs, and hence prices, down by minimizing the variety of both components and products and setting up large production runs. They developed aggressive advertising and employed sales forces to market their products.

An important innovation in operations that made mass production possible was the system of standardized and interchangeable parts known as the "American system of manufacture" (Hounshell, 1984), which developed in the United States and spread to the United Kingdom and other countries. Instead of being produced for a specific machine or piece of equipment, parts were made to a standard design that could be used in different models. This greatly reduced the amount of work required in cutting, filing and fitting individual parts, and meant that people or companies could specialize in particular parts of the production process.

A second innovation was the development by Frederick Taylor (1911) of the system of 'scientific management', which sought to redesign jobs using similar principles to those used in designing machines. Taylor argued that the role of management was to analyze jobs in order to find the 'one best way' of performing any task or sequence of tasks, rather than allowing workers to determine how to perform their jobs. By breaking down activities into tasks that were sequential, logical and easy to understand, each worker would have narrowly defined and repetitious tasks to perform, at high speed and therefore with low costs (Kanigel, 1999).

A third innovation was the development of the moving assembly line by Henry Ford. Instead of workers bringing all the parts and tools to a fixed location where one car was put together at a time, the assembly line brought the cars to the workers. Ford thus extended the ideas of scientific management, with the assembly line controlling the pace of production. This completed the development of a system through which large volumes of standardized products could be assembled by unskilled workers at constantly decreasing costs – the apogee of mass production.

The modern period

Mass production worked well as long as high volumes of mass-produced goods could be produced and sold in predictable and slowly changing markets. However, during the 1970s, markets became highly fragmented, product life cycles reduced dramatically, and consumers had far greater choice than ever before.

An unforeseen challenge to Western manufacturers emerged from Japan. New Japanese production techniques, such as total quality management (TQM), just-in-time (JIT) and employee involvement were emulated elsewhere in the developed world with mixed results. More recently, the mass production paradigm has been replaced, but there is yet no single approach to managing operations that has become similarly dominant. The different approaches for managing operations that are currently popular include:

- **Flexible specialization** (Piore and Sabel, 1984) in which firms (especially small firms) focus on separate parts of the value-adding process and collaborate within networks to produce whole products. Such an approach requires highly developed networks, effective processes for collaboration and the development of long-term relationships between firms.

- **Lean production** (Womack et al., 1990) which developed from the highly successful Toyota Production System. It focuses on the elimination of all forms of waste from a production system. A focus on driving inventory levels down also exposes inefficiencies, reduces costs, and cuts lead times.
- **Mass customisation** (Pine et al., 1993) which seeks to combine high volume, as in mass production, with adapting products to meet the requirements of individual customers. Mass customisation is becoming increasingly feasible with the advent of new technology and automated processes.
- **Agile manufacturing** (Kidd, 1994) which emphasizes the need for an organization to be able to switch frequently from one market-driven objective to another. Again, agile manufacturing has only become feasible on a large scale with the advent of enabling technology.

In various ways, these approaches all seek to combine the high volume and low cost associated with mass production with the product customization, high levels of innovation and high levels of quality associated with craft production.

Table 1.5.1: A chart summarizing characteristics of craft manufacturing, mass productions, and the modern period.

	CRAFT MANUFACTURING (PRIOR TO LATE 1800)	MASS PRODUCTION (LATE 1800-1970)	THE MODERN PERIOD (1970-PRESENT)
PRODUCTION	Low volume	High volume	High volume
VARIETY	Maximal	Minimal	Dependent on company's goals
FOCUS	Meet specific requirements of customers	Low costs and prices, standardization of materials and production	Low costs, adaptability within market, innovation, high quality
WORKERS	Highly skilled and specialized individuals	Many (usually unskilled) individuals with narrowly defined tasks	Dependent on company's goals
FACILITY	Home or small workshops	Fixed locations with assembly lines	Dependent on company's goals
COMPETITION	Low	High	Very high

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1.6: Producing Goods and Services

The production and goods and the performance of services are both part of operations management. There are however some key differences in the two.

In the production of goods the result is the creation of a tangible product such as a vehicle, an article of clothing, a cell phone or a shovel. A service on the other hand is an intangible such as a car repair, a haircut, or a medical treatment. There are some key differences in managing these two types of businesses.

1. Services have a much higher amount of customer contact. The customer will generally come to the service provider for the service to take place, or the service provider will come to the customer.
    - In manufacturing the customer rarely comes to our facility. The purchase generally takes place at a different location than the one where the manufacturing occurred. That simplifies matters quite a bit.
2. Services have a higher amount of labour content than manufacturing organizations.
3. Services have a much higher degree of input variability than do manufacturing companies. Each customer often arrives to a service with a unique set of circumstances that may require extra time and skills on the part of the service provider.
4. Measurement of quality is much more straight-forward in a manufacturing setting. There are many technical ways of deciding if manufactured goods have the required quality level.
    - In services many factors will affect the customers impression of the quality of the service received.
5. Measurement of productivity is very straight-forward in a manufacturing operation due to high degree of standardization in the inputs and outputs used.
    - In services it is more difficult to measure productivity.
6. Inventory can be stored in the case of a manufacturing organization. If goods are not sold in the intended week, then they can be put into storage to be sold at a later date.
    - In services, once the time period has passed, the opportunity to use that capacity is gone.

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1.7: Chapter Key Terms

Agile manufacturing – Emphasizes the need for an organization to be able to switch frequently from one market-driven objective to another.

Craft manufacturing – The production of goods in low volume, but with a high degree of variety, performed by skilled, specialized craftspeople to meet the requirements of their individual customers.

Effectiveness – Making the right actions and plans in order to improve the business and add value for the customer.

Efficiency – Doing things well at the lowest cost possible and reducing activities which add unnecessary costs.

Flexible specialization – Firms (especially small firms) focus on separate parts of the value-adding process and collaborate within networks to produce whole products. Such an approach requires highly developed networks, effective processes for collaboration and the development of long-term relationships between firms.

Lean production – Focuses on the elimination of all forms of waste from a production system, especially from the perspective of keeping inventory levels down to exposes inefficiencies, reduces costs, and cuts lead times.

Macro operations – The overall process within a company's transformation processes, e.g. in a brewery, the macro operation is making beer.

Mass customization – Seeks to combine high volume, as in mass production, with adapting products to meet the requirements of individual customers.

Mass production – The production of goods in high volume with low variety by using standardized parts, a system of scientific management, and assembly lines; rose in popularity in the 19th century.

Micro operations – The detailed transformations that must occur, usually in a specific sequence, for a company to complete their macro operation.

Operations management – The design, management, and improvement of the systems and processes that create the organization's goods or services.

Transformation process – Any activity or group of activities that takes one or more inputs, transforms and adds value to them, and provides outputs for customers or clients, e.g. milk (input) being transformed into cheese or butter (outputs).

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CHAPTER OVERVIEW

2: Operations Strategy

Figure 2.1: Operations Management. (Credit: Chikwenguro / Wikimedia Commons / commons.wikimedia.org/wiki/File:Operations_Management.gif)

Learning Objectives

- Explain each of the key purchasing criteria.
- Differentiate between order qualifiers and order winners.
- Understand the four competitive priorities and common strategies firms use to achieve these priorities.
- Describe the term ‘core competency.’
- Describe the three levels of strategy.
- Know the six categories of operations strategy categories.
- Calculate productivity measures including partial, multi-factor and total productivity.

2.1: Competitiveness
2.2: Strategy
2.3: Productivity
2.4: End of Chapter Problems

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2.1: Competitiveness

We have all competed in various types of activities, perhaps in sports, or school. There may have been prizes or rewards for ranking high in these competitions. Business is no different. We define **competitiveness** as the ability and performance of a firm to sell and supply goods and services in a given market, in relation to the ability and performance of other firms.[1] In other words, how will one firm win over customers in order to become the product or service of choice.

Competitive Advantage and Key Purchasing Criteria

Competitive advantage is the leverage a business has over its competitors. This can be gained by offering clients better and greater value. Advertising products or services with lower prices or higher quality piques the interest of consumers. This is the reason behind brand loyalty, or why customers prefer one particular product or service over another.[2]

Each organization needs to have a deep understanding of their customers and what drives their customers to make purchases. We refer to these as **key purchasing criteria**. They are the factors which customers evaluate and consider when making a product choice.

It is important to keep in mind that the customer is not always a consumer purchasing a good at a store. The customer in many instances may be another business. The city of Toronto may be purchasing heavy duty trucks to use in the landscaping of city parks or Toyota may be searching for a new supplier for automobile glass.

Key Purchasing Criteria include:

Price – Firms need to understand how much the customer will pay for an item. If products are seen to be very similar to one another, the customer will choose based on price.

Quality – Many customers are willing to spend more in order to obtain a product with specific characteristics or brand reputation. Not only are we considering a product with a great design, but also, one that is long lasting and defect free.

Variety – There is a part of the market that value the opportunity to choose from a wide variety of products. They look for options to change the style, colour, dimensions or technical characteristics.

Timeliness – Some customers care greatly about how long it will take to obtain the product or service. For companies' in the transportation business, this will be a key necessity in order to gain new customers. This can also be related to the capability of the company to deliver at the time that they had promised.

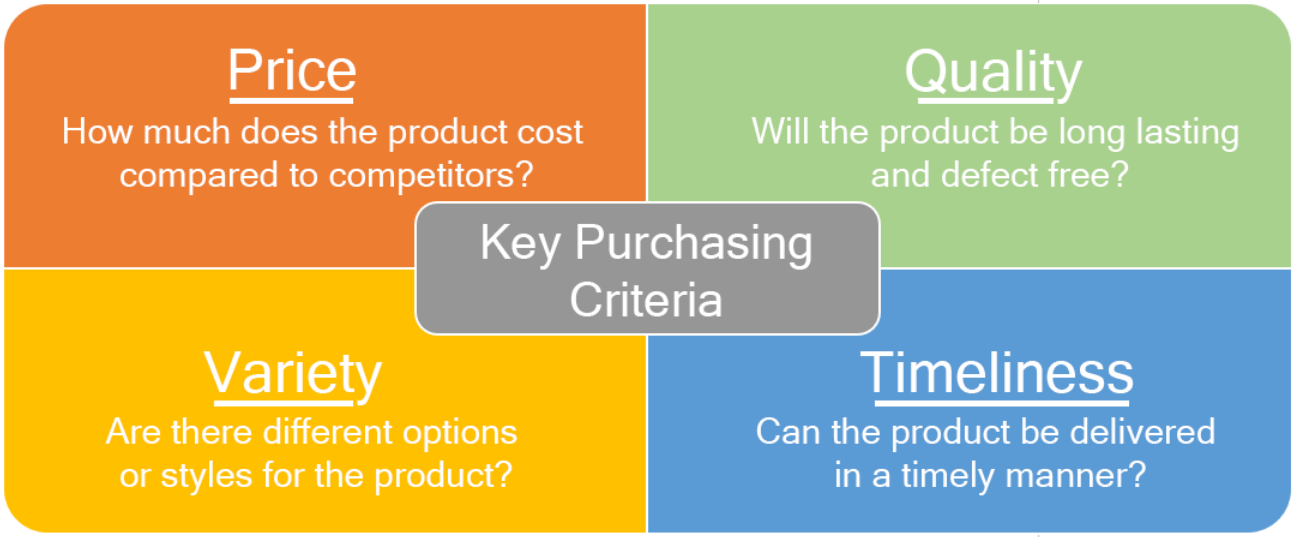

Figure 2.1.1: Categories of key purchasing criteria.

Order qualifiers versus order winners

Two concepts related to key purchasing criteria are order qualifiers and order winners, first introduced by Terry Hill.[3] For important purchases, the customers will consider which characteristics are absolutely necessary (nonnegotiable) and which characteristics can actually lead them to make their decision.

Order qualifiers are those characteristics that are "the nonnegotiable requirements" of the customer. Unless these characteristics are part of the product or service package, the customer will look elsewhere. Order qualifiers for a car may include and minimum safety features, and air conditioning.

An **order winner** is the characteristic that wins the order. Often it may be a new technical feature that is desirable. It could be a great warranty package or service agreement, or a better price.

Order qualifiers and order winners change over time. What was an order winner some years ago, may now become an order qualifier and vice versa. In 1989, air conditioning in a car might have been considered an order winner. It was new and desirable. In 2020 however, few customers purchasing a new car would consider buying a car without air conditioning. It has therefore changed from an order winner to an order qualifier.

Marketing must understand what the order qualifiers and order winners are for their customers. Operations must respond promptly to ensure that they are making these options and features available to customers.

Competitive Priorities

The competitive priorities are the ways in which the Operations Management function focuses on the characteristics of cost, quality, flexibility and speed. The firm's customers will determine which of the competitive priorities are emphasized.

Cost – Firms whose customers prioritize price will be very interested in having processes that enable them to keep their costs low. These companies are typically paying close attention to identifying and eliminating waste within their operations. By reducing defects, they will reduce costs. These firms will closely monitor and seek to improve their productivity. Factors such as resource utilization and efficiency will be important.

Quality – Firms whose customers prioritize quality focus on creating both excellent product and process design. Marketing and Engineering collaborate to design products that meet customers' requirements. Manufacturing must ensure that the process is able to produce the products defect-free. It is only by having excellent design quality and excellent process quality that the organization can ensure that customers will have their expectations satisfied.

Flexibility – Firms whose customers prioritize variety must prioritize the ability to change rapidly. Firms who value flexibility usually do so by carefully choosing equipment that is general-purpose and able to perform multiple functions. They will often strive to keep a small amount of spare capacity in case it is needed. Multi-skilled employees who are able to work in various areas of the firm or operate multiple types of technology are valued. These firms want to ensure that they can get new products to market quickly and transition from making one product to another quickly. Keeping machine set-ups fast is a critical way to do this. They also strive to be able to abruptly modify the volume of their output in case the need or opportunity arises.

Delivery (reliability and speed) – Firms whose customers prioritize speed of product/service delivery must be very efficient and quick at providing their products and services. McDonald's and Amazon are examples of this.

Below is a table summarizing the relationship between a customer's priority and a firm's strategy.[4]

Customer's priority	Firm's strategy
Cost	Minimizing product costs and waste, maximizing productivity
Quality	Designing superior, durable products, minimizing defects
Flexibility	Adaptability in product design and output, utilizing general-purpose machinery and multi-skilled workers
Delivery	Maintaining reliable and speedy delivery services

It is a long-held understanding that each major decision that needs to be made within the operations of an organization will include a trade-off because it is impossible for any one organization to excel on all the competitive priorities at once! An example is a manufacturer who competes on the basis of cost. In order to reduce defects, they may choose to change one of their input components for one with a better quality. This however will increase their costs. Cost and quality are common trade-offs. Flexibility and speed are also considered trade-offs. When organizations increase their number of options and varieties, it adds operational complexity. This will slow down their operations.

Core Competency (Core Capabilities)

Core competency is a management theory that originated in a 1990 Harvard Business Review article, "The Core Competence of the Corporation."

Core competencies are the resources and capabilities that comprise the strategic advantages of a business. A modern management theory argues that a business must define, cultivate, and exploit its core competencies in order to succeed against the competition.

- Core competencies are the defining characteristics that make a business or an individual stand out from the competition.
- Identifying and exploiting core competencies are as important for a new business making its mark as for an established company trying to stay competitive.
- A company's people, physical assets, patents, brand equity, and capital all can make a contribution to a company's core competencies.

A successful business has identified what it can do better than anyone else, and why. Its core competencies are the "why."

Defining Core Competencies

In the article, C.K. Prahalad, and Gary Hamel review three conditions a business activity must meet in order to be a core competency:

- The activity must provide superior value or benefits to the consumer.
- It should be difficult for a competitor to replicate or imitate it.
- It should be rare.

Some examples of core competencies:

- McDonald's has standardization. It serves nine million pounds of French fries every day, and every one of them has precisely the same taste and texture.
- Apple has style. The beauty of its devices and their interfaces gives them an edge over its many competitors.
- Walmart has buying power. The sheer size of its buying operation gives it the ability to buy cheap and undersell retail competitors.[5]

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2.2: Strategy

The Strategy Hierarchy

In most corporations, there are several levels of management. Strategic management is the highest of these levels in the sense that it is the broadest and applies to all parts of the firm while also incorporating the longest time horizon. It gives direction to corporate values, corporate culture, corporate goals, and corporate missions. Under this broad corporate strategy there are typically business-level competitive strategies and functional unit strategies.[1]

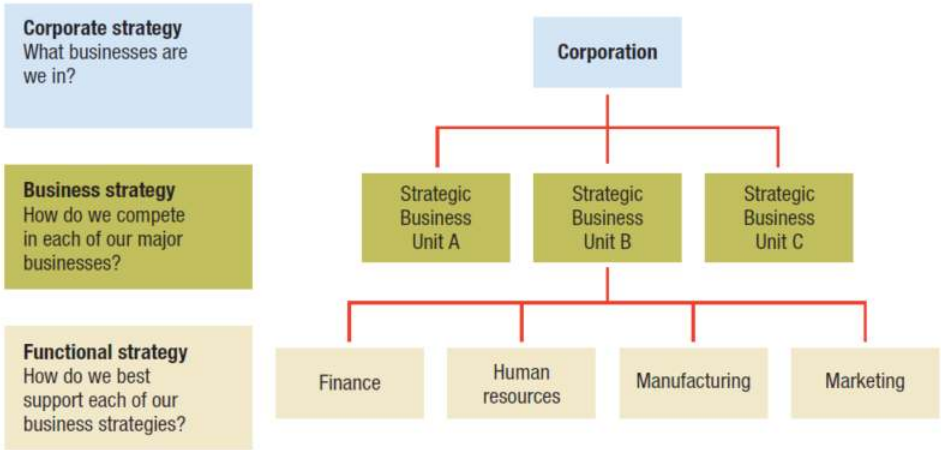

Figure 2.2.1:A hierarchical diagram detailing different strategies within a corporation; Credit: Abey Francis; https://www.mbaknol.com/strategic-ma...egy-hierarchy/

Corporate strategy refers to the overarching strategy of the diversified firm. Such a corporate strategy answers the questions of "in which businesses should we compete?" and "how does being in these businesses create synergy and/or add to the competitive advantage of the corporation as a whole?"

Business strategy refers to the aggregated strategies of a single business firm or a strategic business unit (SBU) in a diversified corporation. According to Michael Porter, a firm must formulate a business strategy that incorporates either cost leadership, differentiation or focus in order to achieve a sustainable competitive advantage and long-term success in its chosen arenas or industries.

Functional strategies include marketing strategies, new product development strategies, human resource strategies, financial strategies, legal strategies, supply-chain strategies, and information technology management strategies. The emphasis is on short- and medium-term plans and is limited to the domain of each department's functional responsibility. Each functional department attempts to do its part in meeting overall corporate objectives, and hence to some extent their strategies are derived from broader corporate strategies.

Many companies feel that a functional organizational structure is not an efficient way to organize activities, so they are reengineered according to processes or SBUs. A **strategic business unit** is a semi-autonomous unit that is usually responsible for its own budgeting, new product decisions, hiring decisions, and price setting. An SBU is treated as an internal profit centre by corporate headquarters.

An additional level of strategy called **operational strategy** was encouraged by Peter Drucker in his theory of Management By Objectives (MBO). It is very narrow in focus and deals with day-to-day operational activities such as scheduling criteria. Operational level strategies are informed by business level strategies which, in turn, are informed by corporate level strategies.[2]

Operations strategy categories can be broken down into many types of areas that must be addressed. The decisions made in these areas will determine whether the business strategy is executed. Below is a list of 10 critical decisions in operations management[8]:

1. **Design of Goods and Services** – The actual design of the product or service will have the largest impact on the cost to produce and the quality to achieve.

2. **Quality** – The way in which the organization will ensure that the product specifications are met. This may include the use of statistical process control, total quality management or Six Sigma.
3. **Process and Capacity Design** – The type of product along with its volume and variety will have the major impact on which type of process to be chosen.
4. **Location** – Important decisions such as how many locations and where to locate them are critical to organization success. This will be a major factor in terms of how quickly the transformation process can take place, and how quickly goods can be shipped to customers.
5. **Layout Design and Strategy** – Consider the placement of work centres, movement of goods, people and information How materials are delivered and used.
6. **Human Resources and Job Design** – Decisions regarding training for employees, how to motivate employees to achieve operational success.
7. **Supply Chain Decisions** – Decisions in terms of where suppliers are located and the level of supplier collaboration are major considerations that impact cost and delivery speed.
8. **Inventory** – How will inventories be used and controlled in the business and the supply chain
9. **Scheduling** – includes both how to schedule production, resources and employees in order to be effective, efficient and meet commitments to customers.
10. **Maintenance**– This involves maintaining equipment and machinery as well as keeping quality high and processes stable.

Common Operations Strategies

There are many types of Operations strategies; two of the most common are quality-based strategies and time-based strategies.

Quality-based strategies are commonly used when companies wish to elevate their reputation in the marketplace. Improving on their product design and the reduction of errors are the backbone of these initiatives. Firms will often use programs such as ISO9001, Six Sigma, and Total Quality Management in their efforts.

Time-based strategies are used to reduce lead time, which is the amount of time elapsed from the receipt of the customer's order until the products are shipped. Firms that can produce faster will often have lower costs. These companies may use lean production methods to improve the velocity of their processes.

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2.3: Productivity

In operations, we love to measure. One of the key ways we judge our operational performance is by using a simple wholistic measure, which is productivity.

Productivity is referred to as a relative measure. It has little meaning in isolation but does tell a story when it is compared to the previous period, or to a similar department or organization. The key thing we pay attention to is whether the productivity has improved or declined or stayed the same. Let's look at several types of productivity measures, and how to calculate the percent change.

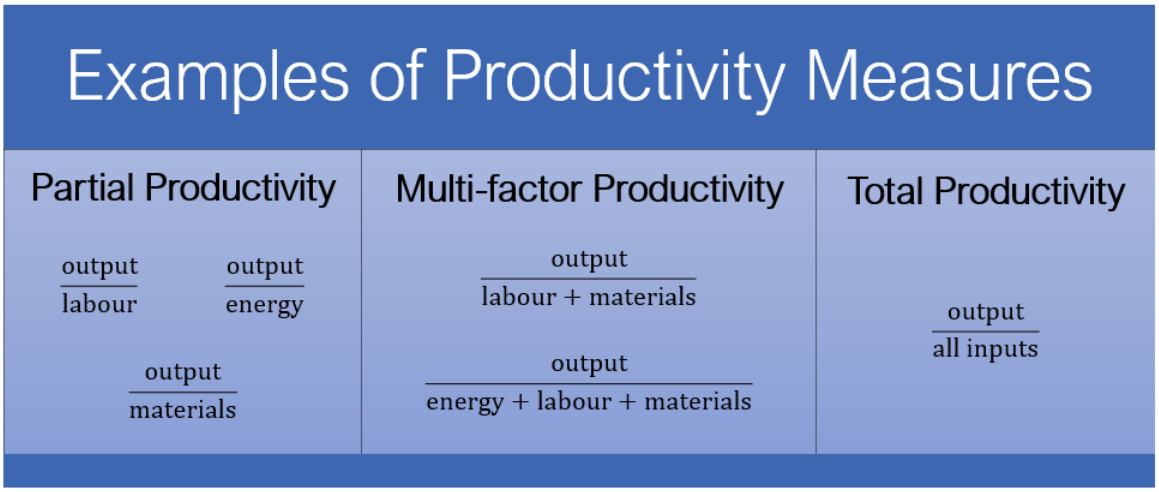

Figure 2.3.1: Examples of equations for productivity measures.

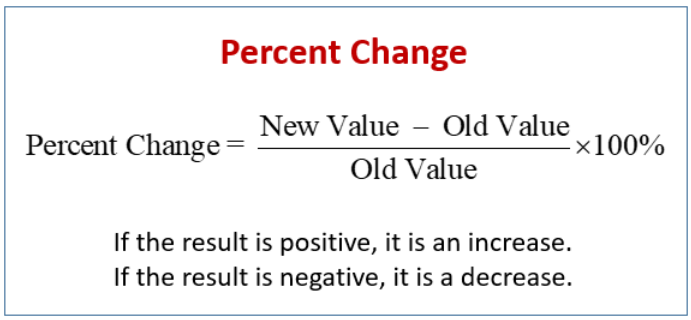

Figure 2.3.2: Percent change calculation; Credit: onlinemathlearning.com/percent-change-algebra.html

Output is always a reflection of how much the firm was able to produce. If the product is homogenous, meaning it has very little variations, then expressing output as the number of units produced may be reasonable. If, however, the firm makes a variety of products with different levels of labour and material costs, then the output would likely be described by the dollar value of all the goods produced within a certain time period.

For **inputs**, dollars spent are typically used as the measure. Several exceptions might be labour hours, gallons of water, or kilowatts of electricity. Firms will typically measure the productivity for the things which represent significant expenditures. A farmer might measure the pounds of meat produced as the output and the pounds of feed consumed as the input. Some other common productivity measures can be found below.

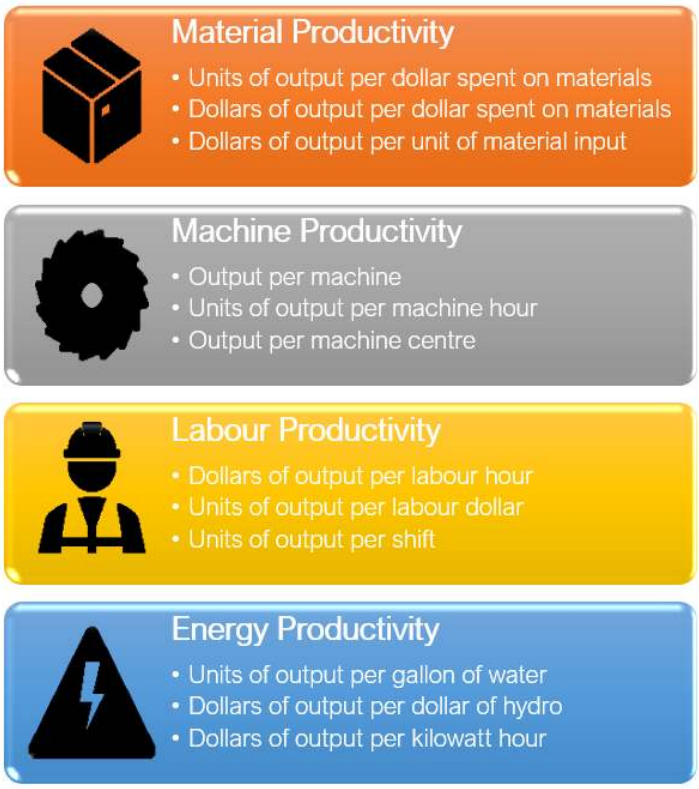

Figure 2.3.3: Examples of productivity measures.

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2.4: End of Chapter Problems

Problem #1

Billco Windows and Doors is preparing their monthly productivity report. Their monthly costs are shown below. Calculate the **a)** labour productivity (output / labour hours), **b)** machine productivity (output / machine hours), and **c)** the multifactor productivity (output / labour cost + material cost + energy cost) of dollars spent on labour, materials, and energy. Average labour rate is $18.00.

Units produced: 1800

Labour hours: 1975

Machine hours: 425

Materials cost: $81000

Energy cost: $21600

Solution

a) Labour productivity (output / labour hours)
= 1800 / 1975
= .91 units per labour hour

b) Machine productivity (output / machine hours)
= 1800 / 425
= 4.23 units per machine hour

c) Multifactor productivity (output / labour cost + material cost + energy cost)
= 1800 / (1975 x $18 + $81000 + $21600)
= .013 units per dollar spent

Problem #2

A company makes seasonal jams and jellies. Yesterday they produced 420 jars of jam with five workers who each worked an 8-hour day. What was the labour productivity?

Solution

= 420 / (5 workers x 8 hours)
= 10.5 jars per worker hour

Problem #3

A greeting card company manufactured 3500 cards in one day. Labour cost was $1200, material cost was $90, and overhead was $450. What is the multifactor productivity?

Solution

= 3500 / ($1200 + $90 + $450)
= 2.01 cards per dollar of input

Problem #4

Joe has purchased a pizza franchise and is learning how to measure productivity. Calculate the **a)** food cost productivity, **b)** labour productivity, and **c)** total productivity. Also calculate the percent change for each measure.

	June	July
Sales	$52500	$59650
Food cost	$15750	$16702
Labour cost	$11550	$14912
Overhead cost	$3500	$3500

Solution

	June	July	% Change
a) Food cost productivity	52500 / 15750 = **$3.33**	59650 / 16702 = **$3.57**	(3.57 – 3.33) / 3.33 x 100 = **+7.21%**
b) Labour productivity	52500 / 11550 = **$4.55**	59650 / 14912 = **$4.00**	(4.00 – 4.55) / 4.55 x 100 = **-12.09%**
c) Total productivity	52500 / (15750 + 11550 + 3500) = **$1.70**	59650 / (16702 + 14912 + 3500) = **$1.70**	(1.70 – 1.70) / 1.70 x 100 = **0%**

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CHAPTER OVERVIEW

3: Making Decisions with Financial Data

Operational Decision Making

Operational decision making is a critical aspect of managing any organization. It involves making choices that affect the day-to-day functioning and long-term strategy of the business. Understanding and utilizing financial data is essential in this process, as it provides a quantitative basis for evaluating options and making informed decisions.

Financial data serves as the backbone of operational decision making. It includes information on costs, revenues, profits, and other key financial metrics. By analyzing this data, managers can identify trends, forecast future performance, and assess the financial impact of different decisions. This helps in setting realistic goals, allocating resources efficiently, and ensuring the financial health of the organization.

When making operational decisions, organizations often face tradeoffs. These tradeoffs can involve balancing short-term gains against long-term sustainability, cost reduction against quality improvement, or speed of implementation against thoroughness of planning. For example, a company might need to decide whether to invest in new technology that could improve efficiency but requires significant upfront costs. Understanding the financial implications of these tradeoffs is crucial for making decisions that align with the organization's strategic objectives.

The function of operations is a significant cost component for businesses. This includes expenses related to production, logistics, labor, and maintenance. Managing these costs effectively is essential for maintaining profitability. Operational decisions, such as optimizing supply chain processes, improving production techniques, or outsourcing certain functions, can have a substantial impact on the overall cost structure of the organization.

Operational decision making is a complex process that requires careful consideration of financial data. By understanding the financial implications of different options, organizations can make informed decisions that balance various tradeoffs and support their strategic goals. Effective management of operational costs is also critical for ensuring long-term success and competitiveness in the market.

3.1: Why Does Understanding Costs Matter?
3.2: Understanding the Cost Equation
3.3: Contribution Margin - the Foundation for CVP
3.4: Calculate the Break-Even Point
3.5: Perform Break-Even Sensitivity Analysis for a Single Product
3.6: Perform Break-Even Sensitivity Analysis for a Multi-Product Environment
3.7: Understanding the Degree of Operating Leverage

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3.1: Why Does Understanding Costs Matter?

Figure 3.1.1: Balancing Cost, Volume, and Profit. Managers employ cost-volume-profit (CVP) analysis to determine the sales level at which they break even or balance their revenue with their expenses. (credit: modification of "Balance Swing Equality" by "Mediamodifier"/Pixabay, CC0)

As president of the Business Students Club, you are working on a fundraiser selling T-shirts on campus, with the funds going towards OzHarvest – a charity providing meals to the less fortunate. You have gotten quotes from several suppliers ranging from $8 to $10 per shirt and now have to select a vendor. The prices vary based on whether the T-shirts have pockets, have long sleeves or short sleeves, and are printed on one side or both. You are confident that you can sell them for $15 each. However, the university will charge a fee of $100 to have a stall on-campus, and your T-shirt sales must cover this cost and any net profit will be donated to charity.

In addition, several of the vendors will give volume discounts—the more shirts you purchase, the less each shirt costs. In short, you need to know exactly which style of T-shirt, vendor, and quantity will allow you to reach your desired net profit and cover your fixed expense of $100. You decide on a short-sleeve shirt with a pocket that costs $10 each and that you can sell for $15.

This $5 per shirt "gross profit" will first go toward covering the $100 student sale fee. That means you will have to sell 20 shirts to pay the fee ($100/$5 = 20 shirts). After selling the first 20 shirts, the $5 profit will be available to start contributing towards your OzHarvest donation. Your goal is to donate $750 which will provide 1500 meals to those in need. This means the t-shirt stall will need to generate an additional $750 on top of the first 20 shirts.

At $5 per shirt you will need to sell 150 shirts to reach your donation target ($750/$5). How many shirts will the club need to sell overall? You will need to sell a total of 170 shirts: 20 to cover your fixed cost of $100 and an additional 150 to cover the donation target ($750).

What you have just completed is a cost-volume-profit analysis. In this chapter, we will explore how managers can use this type of analysis to make a wide range of decisions about their business operations.

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3.2: Understanding the Cost Equation

To be able to complete any cost-volume-profit (CVP) analysis, first we must understand some basic information about costs that businesses incur.

Costs can be classified in many ways – and there can be many starting points in terms of categorizing costs – but let's start with the following classifications:

1. Variable costs
2. Fixed costs
3. Mixed costs

Variable costs change as the quantity of goods or services produced or provided changes. **Fixed costs** are exactly as the name implies – they remain the same regardless of the quantity / volume of goods or services produced within the period. **Mixed costs** are those a combination of variable and fixed components (and when conducting CVP analysis, we will break mixed costs into fixed and variable components).

Consider the following example. Amantha's Artistry (AA) makes sweet treats. Amantha's variable costs are flour, butter, sugar, vanilla essence and other ingredients in her cupcakes. The fixed costs are the rent for her store and public liability insurance. Amantha's mixed costs include her utilities. Electricity for example, has a fixed component (a monthly access charge) and a variable component based on how much electricity is used (which is dependent on how many hours a day the ovens are in use).

> This can be represented in an equation: **Y=a+bx**
>
> where Y is the total cost, a is the fixed cost, b is the variable cost per unit, and x is the level of activity.

The cost equation is a linear equation that takes into consideration total fixed costs, the fixed component of mixed costs, and variable cost per unit. Cost equations can use past data to determine patterns of past costs that can then project future costs, or they can use estimated or expected future data to estimate future costs.

Let's take a more in-depth look at the cost equation by examining the costs incurred by Amantha's Artistry in the manufacture of sweet treats, as shown in the table below.

Cost Information for Amantha's Artistry

Cost Incurred	Fixed or Variable	Cost
Rent on premises	Fixed	$20,000 per year
Public liability insurance	Fixed	$15,000 per year
Ingredients	Variable	$2 per treat
Staff labor	Variable	$1 per treat

By applying the cost equation, Amantha's Artistry can predict its costs at any level of activity (x) as follows:

1. Determine total fixed costs: $30,000 + $15,000 = $35,000
2. Determine variable costs per unit: $2 + $1 = $3
3. Complete the cost equation: Y = $35,000 + 3x$

Using this equation, Amantha's Artistry can now predict its total costs (Y) for any given level of activity (x), as show in the table below:

Treats produced per annum	Cost equation	Total costs
5,000	Y = $35,000 + ($3 x 5,000)	$50,000
12,000	Y = $35,000 + ($3 x 12,000)	$71,000
20,000	Y = $35,000 + ($3 x 20,000)	$95,000

When using this approach, Amantha's Artistry must be certain that it is only predicting costs for its relevant range. For example, if the business expands over 40,000 treats, the business would need to expand and rent a larger premises.

Why do we need to distinguish between fixed and variable costs?

Distinguishing between fixed and variable costs is critical because the total cost is the sum of all fixed costs (the total fixed costs) and all variable costs (the total variable costs). For every unit produced, every customer served, or every hotel room rented, for example, managers can determine their total costs both per unit of activity and in total by combining their fixed and variable costs together.

Figure 3.2.1 illustrates the concept of total costs.

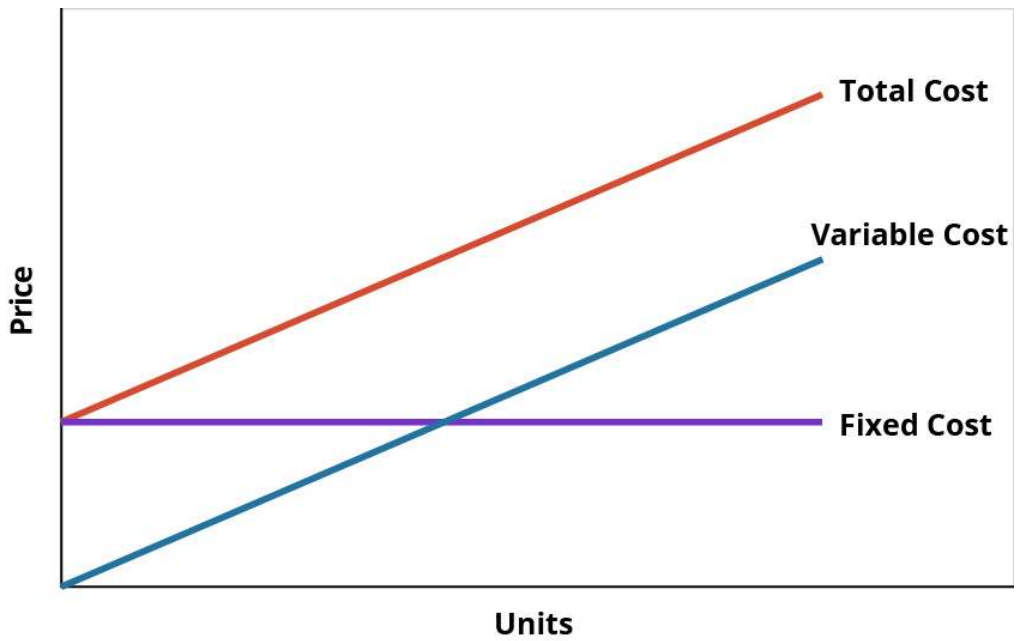

Figure 3.2.1: Total Cost as the Sum of Total Fixed Costs and Total Variable Costs. (attribution: Copyright Rice University, OpenStax, under CC BY-NC-SA 4.0 license)

Remember that the reason that businesses take the time and effort to classify costs as either fixed or variable is to be able to control costs. When they classify costs properly, managers can use cost data to make decisions and plan for the future of the business.

Example - Boeing

If you've ever flown on an airplane, there's a good chance you know Boeing. The Boeing Company generates around $90 billion each year from selling thousands of airplanes to commercial and military customers around the world. It employs around 200,000 people, and it's indirectly responsible for more than a million jobs through its suppliers, contractors, regulators, and others. Its main assembly line in Everett, WA (USA), is housed in the largest building in the world, a colossal facility that covers nearly a half-trillion cubic feet. Boeing is, simply put, a massive enterprise.

And yet, Boeing's managers know the exact cost of everything the company uses to produce its airplanes: every propeller, flap, seat belt, welder, computer programmer, and so forth. Moreover, they know how those costs would change if they produced

more airplanes or fewer. They also know the price at which they sold each plane and the profit the company made on each sale. Boeing's executives expect their managers to know this information, in real time, if the company is to remain profitable.

Test your understanding

Test your understanding of fixed, variable and mixed costs before we move onto using these costs to conduct cost-volume-profit (CVP) analysis.

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3.3: Contribution Margin - the Foundation for CVP

Fixed costs, relevant range and variable costs

To be able to conduct Cost Volume Profit (CVP) analysis, we need to understand something called the **contribution margin**. However, before examining contribution margins, let's review some key concepts: fixed costs, relevant range and variable costs.

Fixed costs are those costs that will not change within a given range of production. For example, in the current case, the fixed costs will be the student sales staff fee of $100. No matter how many shirts the club sells within the relevant range, the fee will be locked in at $100. The relevant range is the anticipated production activity level. Fixed costs remain constant within a relevant range. If production levels exceed expectations, then additional fixed costs will be required (eg have two stalls).

For example, assume that the Club is going to hire a people mover van to get students to a weekend study camp. A people-mover van like a Toyota HiAce People mover will hold twelve passengers, at a cost of $200 per van. If they send one to twelve participants, the fixed cost for the van would be $200. If they send thirteen to twenty four students, the fixed cost would be $400 because they will need two vans. We would consider the relevant range to be between one and twelve passengers, and the fixed cost in this range would be $200. If they exceed the initial relevant range, the fixed costs would increase to $400 for thirteen to twenty four passengers.

Variable costs are those costs that vary per unit of production. Direct materials are often typical variable costs, because you normally use more direct materials when you produce more items. In our example, if the students sold 100 shirts, assuming an individual variable cost per shirt of $10, the total variable costs would be $1,000 (100 × $10). If they sold 250 shirts, again assuming an individual variable cost per shirt of $10, then the total variable costs would $2,500 (250 × $10).

Defining the contribution margin

Contribution margin is the amount by which a product's selling price exceeds its total variable cost per unit. This difference between the sales price and the per unit variable cost is called the contribution margin because it is the per unit contribution toward covering the fixed costs. It typically is calculated by comparing the sales revenue generated by the sale of one item versus the variable cost of the item:

> Contribution Margin = Sales - Variable Costs

In our example, the sales revenue from one shirt is $15 and the variable cost of one shirt is $10, so the individual contribution margin is $5. This $5 contribution margin is assumed to first cover fixed costs first and then any contribution after fixed costs are covered can be considered profit.

As you will see, it is not just small operations, such as the Business Students Club scenario, that benefit from cost-volume-profit (CVP) analysis. At some point, all businesses find themselves asking the same basic questions: How many units must be sold in order to reach a desired income level? How much will each unit cost? How much of the sales price from each unit will help cover our fixed costs?

For example, **Starbucks** faces these same questions every day, only on a larger scale. When they introduce new menu items, such as seasonal specialty drinks, they must determine the fixed and variable costs associated with each item. Adding menu items may not only increase their fixed costs in the short run (via advertising and promotions) but will bring new variable costs. Starbucks needs to price these drinks in a way that covers the variable costs per unit and additional fixed costs and contributes to overall net income. Regardless of how large or small the enterprise, understanding how fixed costs, variable costs, and volume are related to income is vital for sound decision-making.

Starbucks. Large corporations like Starbucks use cost-volume-profit analysis to make decisions about their products and services to ensure that they are maximising their revenues.

Figure 3.3.1: (credit: modification of “StarbucksVaughanMills” by “Raysonho”/Wikimedia Commons, CC0)

Understanding how to use fixed costs, variable costs, and sales in CVP analyses requires an understanding of the term **margin**. You may have heard that restaurants and supermarkets have very low margins, while jewellery stores and furniture stores have very high margins. What does “margin” mean? In the broadest terms, margin is the difference between a product or service’s selling price and its cost of production. Recall the accounting club’s T-shirt sale. The difference between the sales price per T-shirt and the purchase price of the T-shirts was the accounting club’s margin:

Sales Price ($15)

- Cost per T-Shirt ($10)

Margin ($5)

Recall that in the previous section, we explained the characteristics of fixed and variable costs and introduced the basics of cost behavior. Let’s now apply these behaviors to the concept of contribution margin. The company will use this “margin” to cover fixed expenses and hopefully to provide a profit. There are multiple ways to analyse the contribution margin

1. by unit of production
2. as a ratio
3. in total.

Let’s begin by examining contribution margin on a per unit basis.

Unit Contribution Margin

When the contribution margin is calculated on a per unit basis, it is referred to as the contribution margin per unit or unit contribution margin. You can find the contribution margin per unit using the equation shown below:

Contribution margin per unit = Per unit sales price – Variable cost per unit

It is important to note that this unit contribution margin can be calculated either in dollars or as a percentage. To demonstrate this principle, let’s consider the costs and revenues of Leung Manufacturing, a small company that manufactures and sells birdbaths to specialty retailers. The birdbaths are named after recognisable Australian birds such as the Rosella and the Cockatoo.

Figure 3.3.2: Adult Crimson Rosella JJ Harrison (https://www.jjharrison.com.au/), CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons

Leung Manufacturing sells its Rosella Model for $100 and incurs variable costs of $20 per unit. In order to calculate their per unit contribution margin, we use the formula in the table below to determine that on a *per unit* basis, their contribution margin is:

Leung Manufacturing - ROSELLA Model for year ending 30 June 2022	
Sales price per unit	$100
– Variable cost per unit	$20
= Contribution margin per unit	**$80**

This means that for every Rosella model they sell, they will have $80 to *contribute* toward covering fixed costs, such as rent, insurance, and manager salaries.

But Leung Manufacturing manufactures and sells more than one model of birdbath. They also sell a Cockatoo Model for $75, and these birdbaths incur variable costs of $15 per unit. For the Cockatoo Model, their contribution margin on a per unit basis is the $75 sales price less the $15 per unit variable costs is as follows:

Leung Manufacturing - COCKATOO Model for year ending 30 June 2022	
Sales price per unit	$75
– Variable cost per unit	$15
= Contribution margin per unit	**$60**

This demonstrates that, for every Cockatoo model they sell, they will have $60 to *contribute* toward covering fixed costs and, if there is any left, toward profit. Every product that a company manufactures or every service a company provides will have a unique contribution margin per unit.

In these examples, the contribution margin per unit was calculated in dollars per unit, but another way to calculate contribution margin is as a ratio (percentage).

Contribution Margin Ratio

The contribution margin ratio (CMR) is the percentage of a unit's selling price that exceeds total unit variable costs. In other words, contribution margin is expressed as a percentage of sales price and is calculated using this formula:

$$\text{Contribution Margin Ratio} = \frac{\text{Contribution Margin per Unit}}{\text{Sales Price per Unit}}$$

For Leung Manufacturing and their ROSELLA Model, the contribution margin ratio will be

$$\frac{\$80 \text{ Contribution Margin per Unit}}{\$100 \text{ Sales Price per Unit}} = 0.80$$

At a contribution margin ratio of 80%, approximately $0.80 of each sales dollar generated by the sale of a Rosella Model is available to cover fixed expenses and contribute to profit. The contribution margin ratio for the birdbath implies that, for every $1 generated by the sale of a Rosella Model, they have $0.80 that contributes to fixed costs and profit. Thus, 20% of each sales dollar represents the variable cost of the item and 80% of the sales dollar is margin. Just as each product or service has its own contribution margin on a per unit basis, each has a unique contribution margin ratio. Although this process is extremely useful for analysing the profitability of a single product, good, or service, managers also need to see the "big picture" and will examine contribution margin in total across all products, goods, or services.

Another Example of Contribution Margin

You rent a kiosk (a free standing stall) in the local shopping centre for $300 a month and use it to sell T-shirts with sporting team logos from all over the world. You sell each T-shirt for $25, and your cost for each shirt is $15 (including appropriate licensing and royalty fees for using the sporting team logos). You also pay your sales person a commission of $0.50 per T-shirt sold in addition to a salary of $400 per month. Construct a contribution margin income statement for two different months: in one month, assume 100 T-shirts are sold, and in the other, assume 200 T-shirts are sold.

Solution

Pertinent Information		Contribution Margin Income Statement 100 Units Sold		Contribution Margin Income Statement 200 Units Sold	
Sales price per unit	$25	Sales Revenue	$2,500	Sales Revenue	$5,000
Variable costs: Per shirt cost Per shirt commission	 15 0.50	Variable costs per unit ($15 + 0.50) x 100 units	1,550	Variable costs per unit ($15 + 0.50) x 200 units	3,100
		Contribution margin	950	Contribution margin	1,900
Fixed costs: Kiosk rental Salary	 300 400	Fixed costs	700	Fixed costs	700
		Net operating income	$250	Net operating income	$1,200

Total Contribution Margin

This "big picture" is gained by calculating total contribution margin – the total amount by which total sales exceed total variable costs. We calculate total contribution margin by multiplying per unit contribution margin by sales volume or number of units sold.

This approach allows managers to determine how much profit a company is making before paying its fixed expenses. For Leung Manufacturing, if the managers want to determine how much their Rosella Model contributes to the overall profitability of the company, they can calculate total contribution margin as follows:

Leung Manufacturing - ROSELLA Model for month ending 31 May 2022	
Units sold	500 units
Contribution margin per unit	$80
= **Total contribution margin** (500 x $80)	**$40,000**

For the month of May, sales from the Rosella Model contributed $40,000 toward fixed costs. Looking at contribution margin in total allows managers to evaluate whether a particular product is profitable and how the sales revenue from that product contributes to the overall profitability of the company. In fact, we can create a specialized income statement called a contribution margin income statement to determine how changes in sales volume impact the bottom line.

To illustrate how this form of income statement can be used, contribution margin income statements for Leung Manufacturing are shown for the months of May and June, where fixed costs are $23,000 per month.

In May, Leung sold 500 Rosella Models at $100 per unit, which resulted in the operating income shown on the contribution margin income statement:

Leung Manufacturing - Contribution Margin Income Statement for month ending 31 May 2022	
Sales (500 units x $100/unit)	$50,000
Less Variable costs (500 units x $20/unit)	$10,000
CONTRIBUTION MARGIN	**$40,000**
Less Fixed costs	$23,000
Net profit	**$17,000**

In June, 750 of the Rosella models were sold. When comparing the two statements, take note of what changed and what remained the same from May to June.

Leung Manufacturing - Contribution Margin Income Statement for month ending 30 June 2022	
Sales (750 units x $100/unit)	$75,000
Less Variable costs (750 units x $20/unit)	$15,000
CONTRIBUTION MARGIN	**$60,000**
Less Fixed costs	$23,000
Net profit	**$37,000**

Using this contribution margin format makes it easy to see the impact of changing sales volume on operating income. Fixed costs remained unchanged; however, as more units are produced and sold, more of the per-unit sales price is available to contribute to the company's net income.

Before going further, let's note several key points about CVP and the contribution margin income statement.

- First, the contribution margin income statement is used for *internal* purposes and is not shared with external stakeholders.
- Secondly, in this specialized profit and loss/income statement, when net profit is shown, it actually refers to net profit *without regard to income taxes*. Companies can also consider taxes when performing a CVP analysis to project both pre-tax and post-tax profit, however that is beyond the scope of this introductory course on accounting.

Why use three different methods to discuss contribution margin?

Regardless of whether contribution margin is calculated on a per-unit basis, calculated as a ratio, or incorporated into an income statement, all three express how much sales revenue is available to cover fixed expenses and contribute to profit. Let's examine how all three approaches convey the same financial performance, although represented somewhat differently.

You will recall that the per-unit contribution margin was $80 for a Leung Rosella birdbath. When Leung sold 500 units in May, each unit contributed $80 to fixed expenses and profit.

Now, let's use June's Contribution Margin Income Statement as previously calculated to verify the contribution margin based on the contribution margin ratio previously calculated, which was 80%, by applying this formula:

> **Total Sales x Contribution Margin Ratio = Total Contribution Margin**

June sales were $75,000. The Contribution Margin Ratio (CMR) is $0.80. Therefore,

Total Contribution Margin = Total Sales x CMR = $75,000 x $0.80 = $60,000.

This matches with the Contribution margin income statement for June shown above.

Regardless of how contribution margin is expressed, it provides critical information for managers. Understanding how each product, good, or service contributes to the business's profitability allows managers to make decisions such as which product lines they should expand or which might be discontinued. When allocating scarce resources, the contribution margin will help them focus on those products or services with the highest margin, thereby maximising profits.

The Evolution of Cost-Volume-Profit Relationships

The CVP relationships of many organizations have become more complex recently because many labour-intensive jobs have been replaced by or supplemented with technology, changing both fixed and variable costs. For those organizations that are still labour-intensive, the labour costs tend to be variable costs, since at higher levels of activity there will be a demand for more labour usage. For example, assuming one worker is needed for every 50 customers per hour, we might need two workers for an average sales season, but during the Christmas season, the store might experience 250 customers per hour and thus would need five workers.

However, the growing trend in many segments of the economy is to convert labour-intensive enterprises (primarily variable costs) to operations heavily dependent on equipment or technology (primarily fixed costs). For example, in retail, many functions that were previously performed by people are now performed by machines or software, such as the self-checkout machines in stores such as **Woolworths** and **Coles**. Since machine and software costs are often depreciated or amortised, these costs tend to be the same or fixed, no matter the level of activity within a given relevant range.

In China, completely unmanned grocery stores have been created that use facial recognition for accessing the store. Patrons will shop, bag the purchased items, leave the store, and be billed based on what they put in their bags. Along with managing the purchasing process, inventory is maintained by sensors that let managers know when they need to restock an item.

In the United States, Amazon uses Amazon Go stores to offer the same service. Check out this video (copyright owned by CNET) for an example of an Amazon Go store. Note that there are currently 25 Amazon Go stores in the USA, but none in Australia or Asia.

In Australia, COVID19 accelerated the click-and-collect service offered by retailers. Customers can order online from most stores and have it ready to pick up in just a few hours (avoiding potentially long wait times for courier or postal delivery). In some instances, you don't even need to enter the store. Woolworths offers a direct-to-boot service – order your items online and book a window to pick them up. When you arrive, click a button on the app or in the text message you received letting you know your groceries are ready – and someone will bring out your order and place it directly in your boot.

Another major innovation affecting labor costs is the development of driverless cars and trucks (primarily fixed costs), which will have a major impact on the number of taxi and truck drivers in the future (primarily variable costs). The first to be approved for use is the Nuro system in the USA (you can read more about Nuro in this article from CNET). Do these labour-saving processes change the cost structure for the company? Are variable costs decreased? What about fixed costs? Let's look at this in more detail.

When ordering food through an app, there is no need to have an employee take the order, but someone still needs to prepare the food and package it for the customer. The variable costs associated with the wages of order takers will likely decrease, but the fixed costs associated with additional technology to allow for online ordering will likely increase. When grocery customers place their orders online, this not only requires increased fixed costs for the new technology, but it can also increase variable labor costs, as employees are needed to fill customers' online orders. Many stores may move customer-facing positions to online order fulfillment rather than hiring additional employees. Other stores may have employees fill online grocery orders during slow or downtimes. Both Woolworths and Coles operate "dark stores" in Australia – stores that have no customers and are designed only for online order fulfilment.

Using driverless cars and trucks decreases the variable costs tied to the wages of the drivers but requires a major investment in fixed-cost assets – the autonomous vehicles – and companies would need to charge prices that allowed them to recoup their expensive investments in the technology as well as make a profit. Alternatively, companies that rely on shipping and delivery companies that use driverless technology may be faced with an increase in transportation or shipping costs (variable costs). These costs may be higher because technology is often more expensive when it is new than it will be in the future, when it is easier and more cost effective to produce and also more accessible. A good example of the change in cost of a new technological innovation over time is the personal computer, which was very expensive when it was first developed but has decreased in cost significantly since that time. The same will likely happen over time with the cost of creating and using driverless transportation.

You might wonder why a company would trade variable costs for fixed costs. One reason might be to meet company goals, such as gaining market share. Other reasons include being a leader in the use of innovation and improving efficiencies. If a company uses the latest technology, such as online ordering and delivery, this may help the company attract a new type of customer or create loyalty with longstanding customers. In addition, although fixed costs are riskier because they exist regardless of the sales level, once those fixed costs are met, profits grow. All of these new trends result in changes in the composition of fixed and variable costs for a company and it is this composition that helps determine a company's profit.

In order for businesses to remain profitable, it is important for managers to understand how to measure and manage fixed and variable costs for decision-making. In this chapter, we begin examining the relationship among sales volume, fixed costs, variable costs, and profit in decision-making. We will discuss how to use the concepts of fixed and variable costs and their relationship to profit to determine the sales needed to break even or to reach a desired profit. You will also learn how to plan for changes in selling price or costs, whether a single product, multiple products, or services are involved.

What sort of decisions can be made with CVP analysis?

Once you understand variable costs, fixed costs and CVP – the application to internal decision making is vast. The table below provides some examples.

Link between Business Decision and Cost Information Used	
Decision	Cost Information
Discontinue a product line	Variable costs, overhead directly tied to product, potential reduction in fixed costs
Add second production shift	Labor costs, cost of fringe benefits, potential overhead increases (utilities, security personnel)
Open additional retail outlets	Fixed costs, variable operating costs, potential increases in administrative expenses at corporate headquarters

Deciding Between Orders

You are evaluating orders from two new customers, but you will only be able to accept one of the orders without increasing your fixed costs. Management has directed you to choose the one that is most profitable for the company. Customer A is ordering 500 units and is willing to pay $200 per unit, and these units have a contribution margin of $60 per unit. Customer B is ordering 1,000 units and is willing to pay $140 per unit, and these units have a contribution margin ratio of 40%. Which order do you select and why?

Watch this video from Investopedia reviewing the concept of contribution margin to learn more. Keep in mind that contribution margin per sale first contributes to meeting fixed costs and then to profit.

Key Concepts and Summary

- Contribution margin can be used to calculate how much of every dollar in sales is available to cover fixed expenses and contribute to profit.
- Contribution margin can be expressed on a per-unit basis, as a ratio, or in total.
- A specialised profit and loss/income statement, the Contribution Margin Income Statement, can be useful in looking at total sales and total contribution margin at varying levels of activity.

Check your understanding

By completing the following activity:

3.3: Contribution Margin - the Foundation for CVP is shared under a CC BY-NC 4.0 license and was authored, remixed, and/or curated by Amanda White, Mitchell Franklin, Patty Graybeal, Dixon Cooper, and the CDU Business School.

3.4: Calculate the Break-Even Point

Assumptions required for cost-volume-profit analysis

In a previous section, you learned how to determine and recognize the fixed and variable components of costs, and now you have learned about contribution margin. Those concepts can be used together to conduct cost-volume-profit (CVP) analysis, which is a method used by companies to determine what will occur financially if selling prices change, costs (either fixed or variable) change, or sales/production volume changes.

It is important, first, to make several assumptions about operations in order to understand CVP analysis and the associated contribution margin income statement. However, while the following assumptions are typical in CVP analysis, there can be exceptions. For example, while we typically assume that the sales price will remain the same, there might be exceptions where a quantity discount might be allowed. Our CVP analysis will be based on these four (4) assumptions:

1. **Costs are linear and can clearly be designated as either fixed or variable**. In other words, fixed costs remain fixed in total over the relevant range and variable costs remain fixed on a per-unit basis. For example, if a company has the capability of producing up to 1,000 units a month of a product given its current resources, the relevant range would be 0 to 1,000. If they decided that they wanted to produce 1,800 units a month, they would have to secure additional production capacity. While they might be able to add an extra production shift and then produce 1,800 units a month without buying an additional machine that would increase production capacity to 2,000 units a month, companies often have to buy additional production equipment to increase their relevant range. In this example, the production capacity between 1,800 and 2,000 would be an expense that currently would not provide additional contribution toward fixed costs.
2. **Selling price per unit remains constant and does not increase or decrease based on volume** (i.e., customers are not given discounts based on quantity purchased).
3. In the case of manufacturing businesses, inventory does not change because we make the assumption that **all units produced are sold**.
4. In the case of a company that sells multiple products, the **sales mix remains constant**. For example, if we are a beverage supplier, we might assume that our beverage sales are 3 units of coffee pods and two units of tea bags.

Using these assumptions, we can begin our discussion of CVP analysis with the break-even point.

Basics of the break-even point

The break-even point is the dollar amount (total sales dollars) or production level (total units produced) at which the company has recovered all variable and fixed costs. In other words, no profit or loss occurs at break-even because Total Cost = Total Revenue. Figure 3.4.1 illustrates the components of the break-even point:

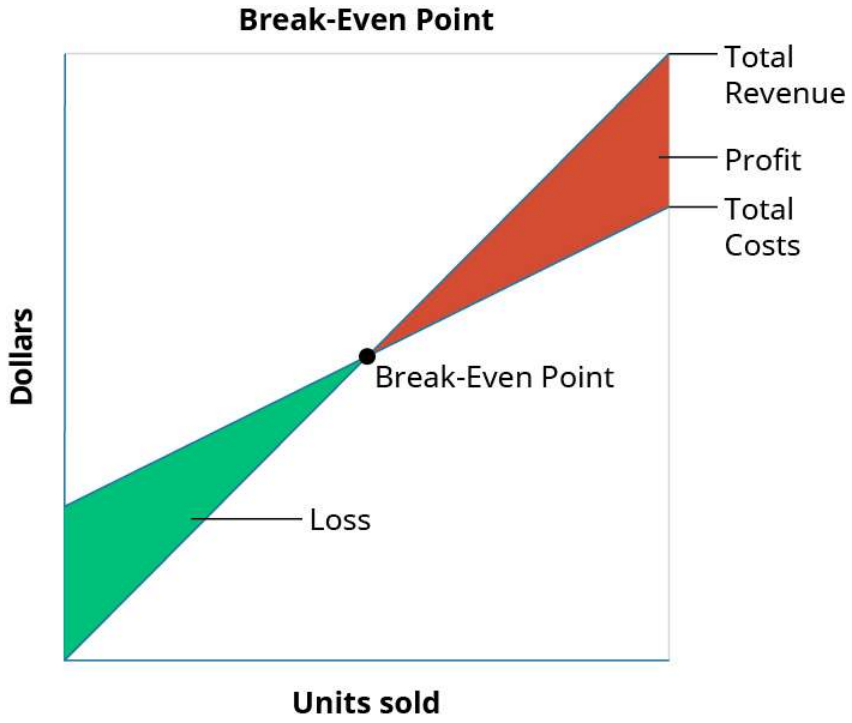

Figure 3.4.1: Break-Even Point. (attribution: Copyright Rice University, OpenStax, under CC BY-NC-SA 4.0 license)

The basic theory illustrated in the diagram above is that, because of the existence of fixed costs in most production processes, in the first stages of production and subsequent sale of the products, the company will report a loss. For example, assume that in an extreme case the company has fixed costs of $20,000, a sales price of $400 per unit and variable costs of $250 per unit, and it sells no units. It would realize a loss of $20,000 (the fixed costs) since it recognised no revenue or variable costs. This loss explains why the company's cost graph recognised costs (in this example, $20,000) even though there were no sales. If it subsequently sells units, the loss would be reduced by $150 (the contribution margin) for each unit sold. This relationship will be continued until we reach the break-even point, where total revenue equals total costs. Once we reach the break-even point for each unit sold the company will see an increase in profits of $150.

For each additional unit sold, the loss typically is lessened until it reaches the break-even point. At this stage, the company is theoretically making neither a profit nor a loss – hence the term "break-even". After the next sale beyond the break-even point, the company will begin to make a profit, and the profit will continue to increase as more units are sold. While there are exceptions and complications that could be incorporated, these are the general guidelines for break-even analysis.

As you can imagine, the concept of the break-even point applies to every business endeavor—manufacturing, retail, and service. Because of its universal applicability, it is a critical concept to managers, business owners, and accountants. When a company first starts out, it is important for the owners to know when their sales will be sufficient to cover all of their fixed costs and begin to generate a profit for the business. Larger companies may look at the break-even point when investing in new machinery, plants, or equipment in order to predict how long it will take for their sales volume to cover new or additional fixed costs. Since the break-even point represents that point where the company is neither losing nor making money, managers need to make decisions that will help the company reach and *exceed* this point as quickly as possible. No business can operate for very long below break-even. Eventually the company will suffer losses so great that they are forced to close their doors.

Break-even analysis and profitability

The first step in determining the viability of the business decision to sell a product or provide a service is analyzing the true cost of the product or service and the timeline of payment for the product or service. Ethical managers need an estimate of a product or service's cost and related revenue streams to evaluate the chance of reaching the break-even point.

Determining an accurate price for a product or service requires a detailed analysis of both the cost and how the cost changes as the volume increases. This analysis includes the timing of both costs and receipts for payment, as well as how these costs will be

financed. An example is an IT service contract for a corporation where the costs will be frontloaded. When costs or activities are frontloaded, a greater proportion of the costs or activities occur in an earlier stage of the project. An IT service contract is typically employee cost intensive and requires an estimate of at least 120 days of employee costs before a payment will be received for the costs incurred. An IT service contract for $100,000 in monthly services with a 30% profit margin will require 4 months of upfront financing of $280,000 balanced over the four months before a single payment is received.

The overall profit at a specific point in time requires a careful determination of all of the costs associated with creating and selling the product or providing the service. An ethical managerial accountant will provide a realistic cost estimate, regardless of management's desire to sell a product or provide a service. What might be a lucrative product on its face needs additional analysis provided by the managerial accountant.

To illustrate the concept of break-even, we will return to Leung Manufacturing and look at the Rosella birdbath they manufacture and sell.

Sales where net profit is $0

Leung Manufacturing is interested in finding out the point at which they break even selling their Rosella Model birdbath. They will break even when the operating income is $0. The operating income is determined by subtracting the total variable and fixed costs from the sales revenue generated by an enterprise. In other words, the managers at Leung want to know how many Rosella birdbaths they will need to sell in order to cover their fixed expenses and break even. Information on this product is:

Leung Manufacturing - Rosella Model – for the year ending 30 June 2022	
Sales Price per Unit	$100
Variable Cost per Unit	$20
CONTRIBUTION MARGIN per Unit	$80
Total Fixed Costs per Month	$18,000

In order to find their break-even point, we will use the contribution margin for the Rosella and determine how many contribution margins we need in order to cover the fixed expenses, as shown in the formula in Figure 3.4.2.

$$\textbf{Break-Even Point in Units: } \frac{\textbf{Total Fixed Costs}}{\textbf{Contribution Margin per Unit}}$$

Figure 3.4.2: Break-Even Point in Units. (attribution: Copyright Rice University, OpenStax, under CC BY-NC-SA 4.0 license)

Applying this to Leung calculates as:

> **Break Even$_{\text{units}}$** = $18,000 / $80 = 225 units

What this tells us is that Leung must sell 225 Rosella Model birdbaths in order to cover their fixed expenses. In other words, they will not begin to show a profit until they sell the 226th unit. This is illustrated in their contribution margin income statement.

Leung Manufacturing - Contribution Margin Income Statement for the year ending 30 June 2022	
Sales (225 units x $100 sales price)	$22,500
Variable Costs (225 units x $20 VC)	$4,500
CONTRIBUTION MARGIN	$18,000
Fixed Costs	$18,000
NET PROFIT	**$0**

The break-even point for Leung Manufacturing at a sales volume of $22,500 (225 units) is shown graphically in the diagram below.

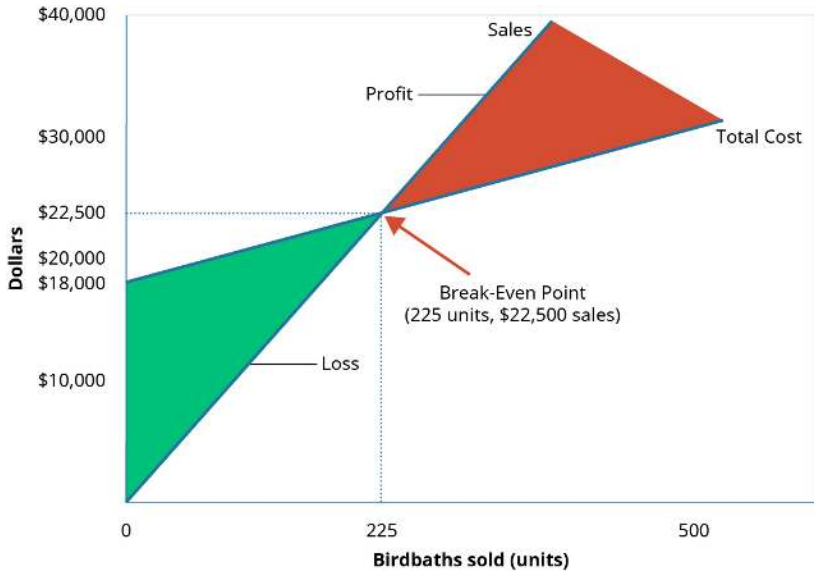

Figure 3.4.3: Break-Even Point for 225 Units. (attribution: Copyright Rice University, OpenStax, under CC BY-NC-SA 4.0 license)

As you can see, when Leung Manufacturing sells 225 Rosella Model birdbaths, they will make no profit, but will not suffer a loss because all of their fixed expenses are covered. However, what happens when they do not sell 225 units? If that happens, the business will make a net loss.

Sales where a loss is made (profit is negative)

In a recent month, local flooding caused Leung to close for several days, reducing the number of units they could ship and sell from 225 units to 175 units. The information in the table below reflects this drop in sales.

Leung Manufacturing - Contribution Margin Income Statement for the year ending 30 June 2022	
Sales (175 units x $100 sales price)	$17,500
Variable Costs (1775 units x $20 VC)	$3,500
CONTRIBUTION MARGIN	$14,000
Fixed Costs	$18,000
NET PROFIT (LOSS)	**($4000)**

At 175 units ($17,500 in sales), Leung does not generate enough sales revenue to cover their fixed expenses and they suffer a loss of $4,000. They did not reach the break-even point of 225 units.

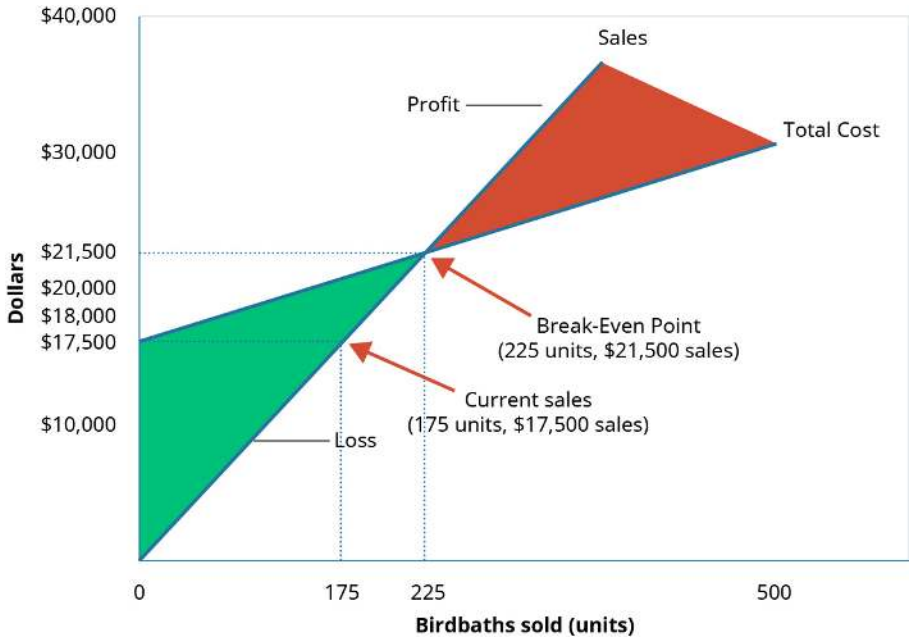

Figure 3.4.4: Break-Even Point for 175 Units. (attribution: Copyright Rice University, OpenStax, under CC BY-NC-SA 4.0 license)

Sales where net profit is positive

What happens when Leung has a busy month and sells 300 Rosella birdbaths? We have already established that the contribution margin from 225 units will put them at break-even. When sales exceed the break-even point the unit contribution margin from the additional units will go toward profit. This is reflected on their income statement.

Leung Manufacturing - Contribution Margin Income Statement for the year ending 30 June 2022	
Sales (300 units x $100 sales price)	$30,000
Variable Costs (300 units x $20 VC)	$6,000
CONTRIBUTION MARGIN	$24,000
Fixed Costs	$18,000
NET PROFIT	**$6,000**

Again, looking at the graph for break-even below, you will see that their sales have moved them beyond the point where total revenue is equal to total cost and into the profit area of the graph.

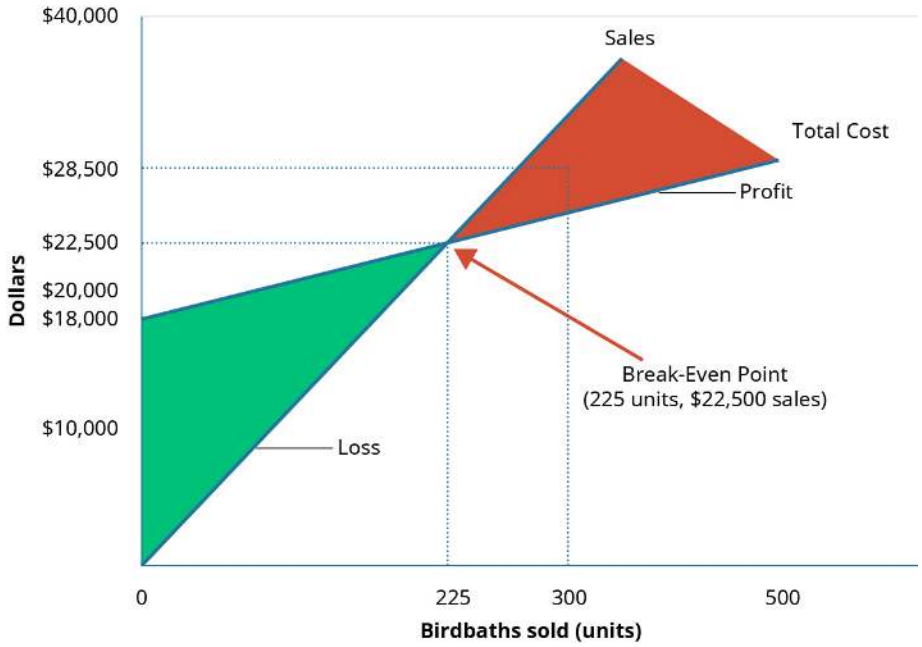

Figure 3.4.4: Break-Even Point for 300 Units. (attribution: Copyright Rice University, OpenStax, under CC BY-NC-SA 4.0 license)

Leung Manufacturing can use the information from these different scenarios to inform many of their decisions about operations, such as sales goals.

However, using the contribution margin per unit is not the only way to determine a break-even point. Recall that we were able to determine a contribution margin expressed in dollars by finding the contribution margin ratio. We can apply that contribution margin ratio to the break-even analysis to determine the break-even point in dollars. For example, we know that Leung had $18,000 in fixed costs and a contribution margin ratio of 80% for the Rosella model. We will use this ratio to calculate the break-even point in dollars.

$$\text{Break-Even Point in Dollars} = \frac{\text{Fixed Costs}}{\text{Contribution Margin Ratio}}$$

Figure 3.4.5: Break-Even Point in Dollars. (attribution: Copyright Rice University, OpenStax, under CC BY-NC-SA 4.0 license)

Applying the formula to Leung gives this calculation:

> **Break-Even point** = $18,000 / 0.80 = $22,500

Leung Manufacturing will have to generate $22,500 in monthly sales in order to cover all of their fixed costs. In order for us to verify that Leung's break-even point is $22,500 (or 225 units) we will look again at the contribution margin income statement at break-even:

Leung Manufacturing - Contribution Margin Income Statement for the year ending 30 June 2022	
Sales (225 units x $100 sales price)	$22,500
Variable Costs (225 units x $20 VC)	$4,500
CONTRIBUTION MARGIN	$18,000
Fixed Costs	$18,000
NET PROFIT	**$0**

By knowing at what level sales are sufficient to cover fixed expenses is critical, but companies want to be able to make a profit and can use this break-even analysis to help them.

Example: The Cost of a Haircut

You are the manager of a hair salon and want to know how many ladies' haircuts your salon needs to sell in a month in order to cover the fixed costs of running the salon. You have determined that, at the current price of $35 per haircut, you have $20 in variable costs associated with each cut. These variable costs include stylist wages, hair product, and shop supplies. Your fixed costs are $3,000 per month. You perform a break-even analysis on a per-unit basis and discover the following:

Sales price per service	$35
Variable cost per service	$20
Contribution margin per service	$15
Break-even (in services)	$200

You have 4 stylists plus yourself working in the salon and are open 6 days per week. Considering the break-even point and the number of available stylists, will the salon ever break even? If it does, what will need to happen? What can be done to achieve the break-even point?

Examples of the effects of variable and fixed costs in determining the break-even point

Companies typically do not want to simply break even, as they are in business to make a profit. Break-even analysis also can help companies determine the level of sales (in dollars or in units) that is needed to make a desired profit. The process for factoring a desired level of profit into a break-even analysis is to add the desired level of profit to the fixed costs and then calculate a new break-even point. We know that Leung Manufacturing breaks even at 225 Rosella birdbaths, but what if they have a target profit for the month of July? They can simply add that target to their fixed costs. By calculating a target profit, they will produce and (hopefully) sell enough bird baths to cover both fixed costs and the target profit.

If Leung wants to earn $16,000 in profit in the month of June, we can calculate their new break-even point as follows:

Target sales = (Fixed costs + Desired Profit) / Contribution Margin per unit
= (18,000 + 16,000) / 80
= **425 units**

We have already established that the $18,000 in fixed costs is covered at the 225 units mark, so an additional 200 units will cover the desired profit (200 units × $80 per unit contribution margin = $16,000). Alternatively, we can calculate this in terms of dollars by using the contribution margin ratio.

Target sales = (Fixed costs + Desired Profit) / Contribution Margin Ratio
= (18,000 + 16,000) / 0.8
= **$42,500**

Note – when you use the Contribution Margin in dollars, the output is in units. When you use the Contribution Margin Ratio, the output is in dollars.

As done previously, we can confirm this calculation using the contribution margin income statement:

Sales (425 units at $100 per unit)	$42,500
Variable Costs (425 units at $20 per unit)	8,500
Contibution Margin	34,000
Fixed Costs	18,000
Operating Income (loss)	$16,000

Application of break-even concepts for a service organization

Because break-even analysis is applicable to any business enterprise, we can apply these same principles to a service business. For example, Marshall & Hirito is a mid-sized accounting firm that provides a wide range of accounting services to its clients but relies heavily on personal income tax preparation for much of its revenue. They have analysed the cost to the firm associated with preparing these returns. They have determined the following cost structure for the preparation of a standard Individual Income Tax Return:

> Charge to Client (sales price per return) = $400
>
> Variable Cost per Return = $150

They have fixed costs of $14,000 per month associated with the salaries of the accountants who are responsible for preparing the tax return In order to determine their break-even point, they first determine the contribution margin for tax return preparation as shown:

> Sales Price per Return = $400
>
> Variable Cost per Return = $150
>
> Contribution Margin per Return = $250

Now they can calculate their break-even point:

> Break-even$_{units}$ = Fixed costs / Contribution margin
> = $14,000 / 250
> = 56 tax returns

Remember, this is the break-even point in units (the number of tax returns) but they can also find a break-even point expressed in dollars by using the contribution margin ratio. First, they find the contribution margin ratio. Then, they use the ratio to calculate the break-even point in dollars:

> Break-even = Fixed costs / Contribution margin ratio
> = $14,000 / 0.625
> = $22,400

We can confirm these figures by preparing a contribution margin income statement:

MARSHALL & SON, CPAs Contribution Margin Income Statement For Year Ended December 31, 2019	
Sales (56 at $400 per return)	$22,400
Variable Costs (56 at $150 per return)	8,400
Contribution Margin	14,000
Fixed costs	14,000
Operating Income (loss)	$ 0

Therefore, as long as Marshall & Hirito prepares 56 tax returns, they will earn no profit but also incur no loss. What if Marshall & Hirito has a target monthly profit of $10,000? They can use the break-even analysis process to determine how many returns they will need to prepare in order to cover their fixed expenses and reach their target profit:

Target returns = (Fixed costs + Target Profit) / Contribution Margin per unit
= (14,000 + 10,000) / 250
= **96 units (or tax returns)**

They will need to prepare 96 returns during the month in order to realize a $10,000 profit. Expressing this in dollars instead of units requires that we use the contribution margin ratio as shown:

Target sales = (Fixed costs + Target Profit) / Contribution Margin Ratio
= (14,000 + 10,000) / 0.625
= **$38,400**

Marshall & Hirito now knows that, in order to cover the fixed costs associated with this service, they must generate $38,400 in revenue. Once again, let's verify this by constructing a contribution margin income statement:

MARSHALL & SON, CPAs Contribution Margin Income Statement For Year Ended December 31, 2019	
Sales (96 at $400 per return)	$38,400
Variable Costs (96 at $150 per return)	14,400
Contribution Margin	24,000
Fixed Costs	14,000
Operating Income (loss)	$10,000

As you can see, the $38,400 in revenue will not only cover the $14,000 in fixed costs, but will supply Marshall & Hirito with the $10,000 in profit (net income) they desire.

As you've learned, break-even can be calculated using either contribution margin per unit or the contribution margin ratio. Now that you have seen this process, let's look at an example of these two concepts presented together to illustrate how either method will provide the same financial results.

Suppose that Channing's Chairs designs, builds, and sells unique ergonomic desk chairs for home and business. Their bestselling chair is the Spine Saver. Figure 3.4.6 illustrates how Channing could determine the break-even point in sales dollars using either the contribution margin per unit or the contribution margin ratio.

Sales Price per Unit	Cost per Unit	Contribution Margin per Unit	Fixed Costs	Fixed Costs/ Contribution Margin per Unit	Break-Even in Units	Break Even in Dollars
$1,250	$850	$400	$16,800	$16,800/$400	42	42 x $1,250 = $52,500

Contribution Margin per Unit ($1,250 – 850)	Contribution Margin Ratio (CM/Sales or $400 ÷ $1,250)	Break-Even in Sales Dollars (FC ÷ CM or $16,800 ÷ 0.32)	Break-Even in Units (Break Even Sales ÷ Unit Selling Price or $52,500 ÷ $1,250)
$400	32%	$52,500	42 Units

Figure 3.4.6: Channing's Break-Even Point. (attribution: Copyright Rice University, OpenStax, under CC BY-NC-SA 4.0 license)

Note that in either scenario, the break-even point is the same in dollars and units, regardless of approach. Thus, you can always find the break-even point (or a desired profit) in units and then convert it to sales by multiplying by the selling price per unit. Alternatively, you can find the break-even point in sales dollars and then find the number of units by dividing by the selling price per unit.

What about incorporating taxes?

So far, we have conducted all of our analysis excluding tax. Tax rates for incorporated business in Australia is 30% (Australian Taxation Office). Therefore, to calculate net profit AFTER tax, we simply deduct 30% from pre-tax net profit in taxes.

We can also incorporate taxes into our Target Profit figure when conducting CVP sensitivity analysis. For example, if a business desires to make $150,500 in profit AFTER tax, then we need to calculate their desired or target profit BEFORE tax. This would be calculated by dividing $150,500 by 70 and multiplying by 100. This is because $150,000 represents 70% of net profit before tax. The desired pre-tax profit would be $215,000.

3.4: Calculate the Break-Even Point is shared under a CC BY-NC 4.0 license and was authored, remixed, and/or curated by Amanda White, Mitchell Franklin, Patty Graybeal, Dixon Cooper, and the CDU Business School.

3.5: Perform Break-Even Sensitivity Analysis for a Single Product

Finding the break-even point or the sales necessary to meet a desired profit is very useful to a business, but cost-volume-profit analysis also can be used to conduct a sensitivity analysis, which shows what will happen if the sales price, units sold, variable cost per unit, or fixed costs change. Businesses use this type of analysis to consider possible scenarios that assist them in planning. It allows businesses to say "what if?" and consider the possible outcomes.

The effects on break-even under changing business conditions

Circumstances often change within a business, within an industry, or even within the economy that impact the decision-making of an organisation. Sometimes, these effects are sudden and unexpected, for example, if a flood destroyed the factory of a business's major supplier; other times, they occur more slowly, such as when union negotiations affect your labour costs. In either of these situations, costs to the business will be affected. Using CVP analysis, the business can predict how these changes will affect profits.

Changing a single variable

To demonstrate the effects of changing any one of these variables, consider Back Door Café, a small coffee shop that roasts its own beans to make coffee. They also sell a variety of baked goods and T-shirts with their logo on them. They track their costs carefully and use CVP analysis to make sure that their sales cover their fixed costs and provide a reasonable level of profit for the owners. There are 3 potential components that could be changed – the sales price, the variable costs or the fixed costs. Let's analyse the impact of a change of each of these (in isolation, not compounded)

Change in sales price

The owner of Back Door has one of her employees conduct a survey of the other coffee shops in the area and finds that competitors are charging $0.75 more for coffee. As a result, the owner wants to determine what would happen to operating income if she increased her price by just $0.50 and sales remained constant, so she performs the following analysis:

Price Change Analysis		
	With Current Price	**With New Price**
Sales Price per Unit	$ 3.75	$ 4.25
Variable Cost per Unit	$ 1.50	$ 1.50
Contribution Margin per Unit	$ 2.25	$ 2.75
Fixed Costs	$2,475	$2,475
Break-even (in units)	1,100	900
Break-Even (in dollars)	$4,125	$3,825
Contribution Margin Income Statement Current Price versus New Price		
Unit Sales, Expected	1,500	1,500
Sales	$5,625	$6,375
Variable Costs	2,250	2,250
Contribution Margin	$3,375	$4,125
Fixed Costs	2,475	2,475
Net Income	$ 900	$1,650

The only variable that has changed is the $0.50 increase in the price of their coffee drinks, but the **net profit/income will increase** by $750. Another way to think of this increase in profit is that, if the sales price increases by $0.50 per coffee drink and the estimated sales are 1,500 units, then this will result in an increase in overall contribution margin of $750. Moreover, since all of the fixed costs were met by the lower sales price, all of this $750 goes to profit. Again, this is assuming the higher sales price does not decrease the number of units sold. Since the other coffee shops will still be priced higher than Back Door, the owner believes that there will not be a decrease in sales volume.

When making this adjustment to their sales price, Back Door Café is engaging in target pricing, a process in which a company uses market analysis and production information to determine the maximum price customers are willing to pay for a good or service. If the good can be produced at a cost that allows both the desired profit percentage as well as deliver the good at a price acceptable to the customer, then the company should proceed with the product; otherwise, the company will not achieve its desired profit goals.

Change in variable cost

In March, the owner of Back Door receives a letter from her cups supplier informing her that there is a $0.05 price increase due to higher material prices. Assume that the example uses the original $3.75 per unit sales price. The owner wants to know what would happen to net profit/income if she absorbs the cost increase (not passing it on to her customers), so she performs the following analysis:

Variable Cost Change Analysis		
	With Current Price	**With Increased Variable Cost**
Sales Price per Unit	$ 3.75	$ 3.75
Variable Cost per Unit	$ 1.50	$ 1.55
Contribution Margin per Unit	$ 2.25	$ 2.20
Fixed Costs	$2,475	$ 2,475
Break-even in Units	1,100	1,125
Break-even in Dollars	$4,125	$4,218.75
Monthly Contribution Margin Income Statement Current Variable Costs versus Increased Variable Costs		
Unit Sales, Expected	1,500	1,500
Sales	$5,625	$ 5,625
Variable Costs	2,250	2,325
Contribution Margin	$3,375	$ 3,300
Fixed Costs	2,475	2,475
Net Income	$ 900	$ 825

She is surprised to see that just a $0.05 increase in variable costs (cups) will **reduce her net income** by $75. The owner may decide that she is fine with the lower income, but if she wants to maintain her income, she will need to find a new cup supplier, reduce other costs, or pass the price increase on to her customers. Because the increase in the cost of the cups was a variable cost, the impact on net profit/income can be seen by taking the increase in cost per unit, $0.05, and multiplying that by the units expected to be sold, 1,500, to see the impact on the contribution margin, which in this case would be a decrease of $75. This also means a decrease in net income of $75.

Change in fixed cost

Back Door Café's lease is coming up for renewal. The owner calls the landlord to indicate that she wants to renew her lease for another 5 years. The landlord is happy to hear she will continue renting from him but informs her that the rent will increase $225 per month. She is not certain that she can afford an additional $225 per month and tells him she needs to look at her numbers and will call him back. She pulls out her CVP spreadsheet and adjusts her monthly fixed costs upwards by $225. Assume that the example uses the original $3.75 per unit sales price for coffee drinks. The results of her analysis of the impact of the rent increase on her annual net income are:

Fixed Cost Change Analysis		
	With Current Price	**With Increased Fixed Cost**
Sales Price per Unit	$ 3.75	$ 3.75
Variable Cost per Unit	$ 1.50	$ 1.50
Contribution Margin per Unit	$ 2.25	$ 2.25
Fixed Costs	$2,475	$2,700
Break-even in Units	1,100	1,200
Break-even in Dollars	$4,125	$4,500
Monthly Contribution Margin Income Statement Current Fixed Costs versus Increased Fixed Costs		
Unit Sales, Expected	1,500	1,500
Sales	$5,625	$5,625
Variable Costs	2,250	2,250
Contribution Margin	$3,375	$3,375
Fixed Costs	2,475	2,700
Net Income	$ 900	$ 675

Because the rent increase is a change in a fixed cost, the contribution margin per unit remains the same. However, **the break-even point in both units and dollars increase** because more units of contribution are needed to cover the $225 monthly increase in fixed costs. If the owner of the Back Door agrees to the increase in rent for the new lease, she will likely look for ways to increase the contribution margin per unit to offset this increase in fixed costs.

In each of the prior examples, only one variable was changed— sales price, variable costs, or fixed costs. There are some generalizations or rules of thumb that can be made regarding how a change in any one of these variables affects the break-even point. These general rules of thumb are summarized in the table below

Rules of thumb regarding changes in break-even point from a change in one variable	
Condition	Result
Sales Price Increases	Break-Even Point Decreases (Contribution Margin is Higher, Need Fewer Sales to Break Even)
Sales Price Decreases	Break-Even Point Increases (Contribution Margin is Lower, Need More Sales to Break Even)
Variable Costs Increase	Break-Even Point Increases (Contribution Margin is Lower, Need More Sales to Break Even)
Variable Costs Decrease	Break-Even Point Decreases (Contribution Margin is Higher, Need Fewer Sales to Break Even)
Fixed Costs Increase	Break-Even Point Increases (Contribution Margin Does Not Change, but Need More Sales to Meet Fixed Costs)
Fixed Costs Decrease	Break-Even Point Decreases (Contribution Margin Does Not Change, but Need Fewer Sales to Meet Fixed Costs)

Watch this video that walks through, step by step, how to calculate break even in units and dollars and at a desired profit or sales level to learn more.

Changing multiple variables

We have analyzed situations in which one variable changes, but often, more than one change will occur at a time. For example, a business may need to lower its selling price to compete, but they may also be able to lower certain variable costs by switching suppliers.

Suppose Back Door Café has the opportunity to purchase a new espresso machine that will reduce the amount of coffee beans required for an espresso drink by putting the beans under higher pressure. The new machine will cost $15,000, but it will decrease the variable cost per cup by $0.05. The owner wants to see what the effect will be on the net income and break-even point if she purchases the new machine. She has arranged financing for the new machine and the monthly payment will increase her fixed costs by $400 per month. When she conducts this analysis, she gets the following results:

Variable Cost and Fixed Cost Change Analysis		
	With Current Price	With Decreased VC and Increased FC
Sales Price per Unit	$ 3.75	$ 3.75
Variable Cost per Unit	$ 1.50	$ 1.45
Contribution Margin per Unit	$ 2.25	$ 2.30
Fixed Costs	$ 2,475	$ 2,875
Break-even in Units	1,100	1,250
Break-even in Dollars	$4,125.00	$4,687.50

Monthly Contribution Margin Income Statement Current Fixed Costs versus Increased Fixed Costs		
Unit Sales, Expected	1,500	1,500
Sales	$ 5,625	$ 5,625
Variable Costs	2,250	2,175
Contribution Margin	$ 3,375	$ 3,450
Fixed Costs	2,475	2,875
Net Income	$ 900	$ 575

Looking at the "what-if" analysis, we see that the contribution margin per unit increases because of the $0.05 reduction in variable cost per unit. As a result, she has a higher total contribution margin available to cover fixed expenses. This is good, because the monthly payment on the espresso machine represents an increased fixed cost. Even though the contribution margin ratio increases, it is not enough to totally offset the increase in fixed costs, and her monthly break-even point has risen from $4,125.00 to $4,687.50. If the new break-even point in units is a realistic number (within the relevant range), then she would decide to purchase the new machine because, once it has been paid for, her break-even point will fall and her net profit/income will rise. Performing this analysis is an effective way for managers and business owners to look into the future, so to speak, and see what impact business decisions will have on their financial position.

Let's look at another option the owner of the Back Door Café has to consider when making the decision about this new machine. What would happen if she purchased the new machine to realize the variable cost savings and also raised her price by just $0.20? She feels confident that such a small price increase will go virtually unnoticed by her customers but may help her offset the increase in fixed costs. She runs the analysis as follows:

Selling price, variable cost, and fixed cost change analysis			
	With Current Price	With decreased VC and increased FC	With increased SP, decreased VC, and increased FC
Sales price per unit	$ 3.75	$ 3.75	$ 3.95
Variable cost per unit	$ 1.50	$ 1.45	$ 1.45
Contribution margin per unit	$ 2.25	$ 2.30	$ 2.50
Fixed costs	$ 2,475	$ 2,875	$ 2,875
Break-even in units	1,100	1,250	1,150
Break-even in dollars	$4,125.00	$4,687.50	$4,542.50
Monthly contribution margin income statement			
Unit sales, expected	1,500	1,500	1,500
Sales	$ 5,625	$ 5,625	$ 5,925
Variable costs	2,250	2,175	2,175
Contribution margin	$ 3,375	$ 3,450	$ 3,750
Fixed costs	2,475	2,875	2,875
Net income	$ 900	$ 575	$ 875

The analysis shows the expected result: an increase in the per-unit contribution margin, a decrease in the break-even point, and an increase in the net operating income. She has changed three variables in her costs – sales price, variable cost, and fixed cost. In fact, the small price increase almost gets her back to the net profit/ income she was expecting before the purchase of the new espresso machine.

By now, you should begin to understand why CVP analysis is such a powerful tool. The owner of Back Door Café can run an unlimited number of these what-if scenarios until she meets the financial goals for her company. There are very few tools in managerial accounting as powerful and meaningful as a cost-volume-profit analysis.

How can they sell it that cheap?

If you've ever needed a caffeine boost but are low on cash in Australia, you will have likely thought about purchasing a $1 coffee from any 7 Eleven convenience store or at a Woolworths or Coles metro store. But how can they sell coffee so cheaply?

Volume! Although the margin on each unit is very small, these stores hope to make up the difference in quantity. They also hope that consumers will purchase other items while in the store – a donut, some fruit, a chocolate bar or chips – where the margins are much higher for each individual item.

Free tools and templates

Rather than creating sensitivity analysis by hand – you can use an excel template like this one

Break even and CVP analysis – single product

Test your understanding

By completing the following multiple choice questions in relation to sensitivity analysis:

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3.6: Perform Break-Even Sensitivity Analysis for a Multi-Product Environment

Up to this point in our CVP analysis, we have assumed that a business only sells one product, but we know that, realistically, this is not the case. Most businesses operate in a multi-product environment, in which they sell different products, manufacture different products, or offer different types of services. Businesses price each one of their products or services differently, and the costs associated with each of those products or services vary as well. In addition, companies have limited resources, such as time and labour, and must decide which products to sell or produce and in what quantities, or which services to offer in order to be the most profitable. These profitability considerations are often helps a business **decide on its sales mix** – the rough proportions of their products that they plan to sell.

The basics of break-even analysis in a multi-product environment

In order to perform a break-even analysis for a company that sells multiple products or provides multiple services, it is important to understand the **concept of a sales mix**. A sales mix represents the relative proportions of the products that a company sells—in other words, the percentage of the company's total revenue that comes from product A, product B, product C, and so forth. Sales mix is important to business owners and managers because they seek to have a mix that maximises profit, since not all products have the same profit margin. Businesses can maximise their profits if they are able to achieve a sales mix that is heavy with high-margin products, goods, or services. If a company focuses on a sales mix heavy with low-margin items, overall profitability will often suffer.

Performing a break-even analysis for these multi-product businesses is more complex because each product has a different selling price, a different variable cost, and, ultimately, a different contribution margin. We must also proceed under the assumption that the sales mix remains constant; if it does change, the CVP analysis must be revised to reflect the change in sales mix. For the sake of clarity, we will also assume that all costs are companywide costs, and each product contributes toward covering these companywide costs.

Example: Selling Sandwiches

You are the manager of a sandwich shop located near a university campus. The university has recently added a fast-food style café to the university food court, which has reduced the number of students eating at your shop. Your highest margin items are drinks (a contribution margin of approximately 90%) and vegetarian subs (a contribution margin of approximately 75%). How can you use CVP analysis to help you compete with the university's food court cafe? What would you suggest as possible ways to increase business while maintaining target income levels?

To conduct appropriate CVP analysis we need to know

- contribution margin for each product
- the existing sales mix of products

Calculating break-even analysis in a multi-product environment

When a business sells more than one product or provides more than one service, break-even analysis is more complex because not all of the products sell for the same price or have the same costs associated with them: Each product has its own margin. Consequently, the break-even point in a multi-product environment depends on the mix of products sold. Further, when the mix of products changes, so does the break-even point. If demand shifts and customers purchase more low-margin products, then the break-even point rises. Conversely, if customers purchase more high-margin products, the break-even point falls. In fact, even if total sales dollars remain unchanged, the break-even point can change based on the sales mix. Let's look at an example of how break-even analysis works in a multi-product environment.

In multi-product CVP analysis, the company's sales mix is viewed as a composite unit, a selection of discrete products associated together in proportion to the sales mix. The composite unit is not sold to customers but is a concept used to calculate a weighted average unit contribution margin, which is then used to estimate the break-even point. Think of a weighted average unit as a virtual basket of fruit that contains the proportion of individual fruits equal to the company's sales mix. If we purchased these items individually to make the fruit basket, each one would have a separate price and a different contribution margin. This is how a

weighted average unit works in CVP analysis. We calculate the contribution margins of all of the component parts of the weighted average unit and then use the total to calculate the break-even point. It is important to note that fixed costs are allocated among the various components (products) that make up this weighted average unit. Should a product be eliminated from the weighted average unit or sales mix, the fixed costs must be re-allocated among the remaining products.

If we use the fruit basket as an example, we can look at the individual fruits that make up the basket: apples, oranges, bananas, and pears. We see that each individual fruit has a selling price and a cost. Each fruit has its own contribution margin. But how would we determine the contribution margin for a weighted average of fruit, or in other words, for our basket of fruit?

For our particular baskets, we will use 5 apples, 3 oranges, 2 bananas, and 1 pear. This means that our product mix is 5:3:2:1, as shown in (Figure 3.6.1.

Fruit	Number of Units	Selling Price per Unit	Total Selling Price	Cost per Unit	Total Cost	Contribution Margin
Apple	5	$0.60	$3.00	$0.25	$1.25	$1.75
Orange	3	1.00	3.00	0.75	2.25	0.75
Banana	2	0.80	1.60	0.50	1.00	0.60
Pear	1	1.90	1.90	1.50	1.50	0.40
Total			$9.50		$6.00	$3.50

Figure 3.6.1: Contribution Margin Based on Product Mix. (attribution: Copyright Rice University, OpenStax, under CC BY-NC-SA 4.0 license)

Notice that the composite contribution margin is based on the number of units of each item that is included in the composite item. If we change the composition of the basket, then the composite contribution margin would change even though contribution margin of the individual items would not change. For example, if we only include 4 apples, the contribution margin of a single apple is still $0.35, but the contribution margin of the apples in the basket is $1.40, not $1.75 as it is when 5 apples are included in the basket. Let's look at an additional example and see how we find the break-even point for this weighted average basket.

Practical example

Let's meet Soul Sisters – they are a social enterprise who work with refugee women to help develop their seamstress skills while producing ethical fashion. They currently make three clothing items – a long sleeve blouse, a pair of work pants and a work skirt with pockets. Each item has its own sales price, variable cost and contribution margin, as shown below:

Clothing	Sales price per item	Variable cost per item	Contribution margin
Long sleeve blouse	$150	$75	$75
Work pants	$140	$50	$90
Work skirt	$115	$65	$50

The sales mix is that if the business sold 10 products – 6 would be blouses, 3 would be work pants and 1 would be a work skirt.

Our next step is to calculate a weighted average contribution margin:

Clothing	Contribution margin	Mix	Weighted contribution margin (CM x Mix)
Long sleeve blouse	$75	60%	$45
Work pants	$90	30%	$27
Work skirt	$50	10%	$5
Weighted average contribution margin for one unit			**$77**

What is the break even point? To do this, we need to know the fixed costs. Soul Sisters tells us that fixed costs are $13,860. We use the weighted average contribution margin in the same way as we would use the contribution margin to calculate the break even point:

> **Break even$_{\text{units}}$** = Fixed costs / Weighted average contribution margin
> = $13,860 / $77
> = 180 units

However, we don't actually sell this weighted average unit. So we need to break up the 180 units into the 3 different products using our mix of 60%. 30% and 10%.

Clothing	Total break even units	Mix	Break even sales in units
Long sleeve blouse	180	60%	108
Work pants	180	30%	54
Work skirt	180	10%	18

Using a forecasted or estimated contribution margin income statement, let's verify that the break even sales in units at Soul Sisters is correct.

SOUL SISTERS - Forecasted Contribution Margin Income Statement

Category	Amount
Sales	
Long sleeve blouse (108 x $75)	16,200
Work pants (54 x $90)	7,560
Work skirt (18 x $50)	2,070
Total sales	**25,830**
Less Variable Costs	
Long sleeve blouse (108 x $75)	8,100
Work pants (54 x $50)	2,700
Work skirt (18 x $65)	1,170
Total variable costs	**11,970**
CONTRIBUTION MARGIN	13,860
Fixed costs	13,860
NET PROFIT/INCOME	**0**

Soul Sisters can use this CVP analysis for a wide range of business decisions and for planning purposes. Remember, however, that if the sales mix changes from its current ratio, then the break-even point will change. For planning purposes, Soul Sisters can

change the sales mix, sales price, or variable cost of one or more of the products in the composite unit and perform a “what-if” analysis.

One way that businesses can easily conduct this analysis is by building a CVP sensitivity analysis template. We’ve provided one for you below that can be used in various situations.

Break even and CVP analysis – multi-product

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3.7: Understanding the Degree of Operating Leverage

What is the degree of operating leverage?

Degree of Operating Leverage (DOL) is a measure of the proportion of fixed costs to a business's overall cost structure. OL tells a business how sensitive profit is to changes in sales volume. The formula for DOL is as follows:

Degree of Operating Leverage = Contribution Margin
…….Net profit or income

How can we use the operating leverage statistic?

The Degree of Operating Leverage (DOL) statistic is most often used to compare different businesses, rather than as a tool for sensitivity analysis for a single firm. Let's try an example using two cafes – Stockmarket Cafe and Universal Cafe.

Finance	Stockmarket Cafe	Universal Cafe
Total contribution margin	180,000	180,000
Net income or profit	90,000	120,000
Operating leverage (= CM / Net income)	2	1.5

Now we have our DOL for both firms – Stockmarket is 2 and Universal is 1.5. What on earth does this mean? It means that for Stockmarket Cafe, if sales increase (or decrease), net income or profit will increase (or decrease) by 2 times the percentage change. That is, if sales increases by 10%, then profit will increase by 20%. Looking at Universal Cafe, if sales increase (or decrease), net income or profit will increase (or decrease) by 1.5 times the percentage change. Using the same 10% increase in sales, at Universal Cafe, profit will increase by 15% (1.5 x 10%).

Which of these two firms is the better investment? Stockmarket Cafe or Universal Cafe?

Is it as simple as higher is better?

No! Remember that Operating Leverage uses contribution margin, and does not take into account any fixed costs. So while OL is one number, it should be looked at in conjunction with other measures. Businesses that have high fixed costs and lower variable costs (one reason could be high levels of automated machinery) will have a higher operating leverage. Businesses that have higher variable costs and therefore lower operating leverage, may have lower fixed costs. To make a more informed decision – examining the number of units to be sold to break even could be useful in assessing which firm may be a better investment.

Investopedia haş produced a summary video about the Degree of Operating Leverage [link opens a YouTube video]

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CHAPTER OVERVIEW

4: Forecasting

Learning Objectives

- What is forecasting and why is it important?Understand the differences between qualitative and quantitative forecasting.
- Describe types of demand patterns exhibited in product demand.
- Calculate forecasts using time series analysis and seasonal index.
- Determine forecast accuracy.

4.1: Introduction to Forecasting
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4.1: Introduction to Forecasting

Forecasting is the process of making predictions of the future based on past and present data. This is most commonly by analysis of trends. A commonplace example might be estimation of some variable of interest at some specified future date. Prediction is a similar, but more general term. Both might refer to formal statistical methods employing time series, cross-sectional or longitudinal data, or alternatively to less formal judgmental methods. Usage can differ between areas of application: for example, in hydrology, the terms “forecast” and “forecasting” are sometimes reserved for estimates of values at certain specific future times, while the term “prediction” is used for more general estimates, such as the number of times floods will occur over a long period.

Risk and uncertainty are central to forecasting and prediction; it is generally considered good practice to indicate the degree of uncertainty attached to specific forecasts. In any case, the data must be up to date in order for the forecast to be as accurate as possible. In some cases, the data used to predict the variable of interest is itself forecasted.[1]

As discussed in the previous chapter, functional strategies need to be aligned and supportive to the higher level corporate strategy of the organization. One of these functional areas is marketing. Creating marketing strategy is not a single event, nor is the implementation of marketing strategy something only the marketing department has to worry about.

When the strategy is implemented, the rest of the company must be poised to deal with the consequences. An important component in this implementation is the **sales forecast**, which is the estimate of how much the company will actually sell. The rest of the company must then be geared up (or down) to meet that demand. In this module, we explore forecasting in more detail, as there are many choices that can be made in developing a forecast.

Accuracy is important when it comes to forecasts. If executives overestimate the demand for a product, the company could end up spending money on manufacturing, distribution, and servicing activities it won’t need. Data Impact, a software developer, recently overestimated the demand for one of its new products. Because the sales of the product didn’t meet projections, Data Impact lacked the cash available to pay its vendors, utility providers, and others. Employees had to be terminated in many areas of the firm to trim costs.

Underestimating demand can be just as devastating. When a company introduces a new product, it launches marketing and sales campaigns to create demand for it. But if the company isn’t ready to deliver the amount of the product the market demands, then other competitors can steal sales the firm might otherwise have captured. Sony’s inability to deliver the e-Reader in sufficient numbers made Amazon’s Kindle more readily accepted in the market; other features then gave the Kindle an advantage that Sony is finding difficult to overcome.

The firm has to do more than just forecast the company’s sales. The process can be complex, because how much the company can sell will depend on many factors such as how much the product will cost, how competitors will react, and so forth. Each of these factors has to be taken into account in order to determine how much the company is likely to sell. As factors change, the forecast has to change as well. Thus, a sales forecast is actually a composite of a number of estimates and has to be dynamic as those other estimates change.

A common first step is to determine market potential, or total industry-wide sales expected in a particular product category for the time period of interest. (The time period of interest might be the coming year, quarter, month, or some other time period.) Some marketing research companies, such as Nielsen, Gartner, and others, estimate the market potential for various products and then sell that research to companies that produce those products.

Once the firm has an idea of the market potential, the company’s sales potential can be estimated. A firm’s sales potential is the maximum total revenue it hopes to generate from a product or the number of units of it the company can hope to sell. The sales potential for the product is typically represented as a percentage of its market potential and equivalent to the company’s estimated maximum market share for the time period. In your budget, you’ll want to forecast the revenues earned from the product against the market potential, as well as against the product’s costs.[2]

Forecasting Horizons

Long term forecasting tends to be completed at high levels in the organization. The time frame is generally considered longer than 2 years into the future. Detailed knowledge about the products and markets are required due to the high degree of uncertainty. This

is commonly the case with new products entering the market, emerging new technologies and opening new facilities. Often no historical data is available.

Medium term forecasting tends to be several months up to 2 years into the future and is referred to as intermediate term. Both quantitative and qualitative forecasting may be used in this time frame.

Short term forecasting is daily up to months in the future. These forecasts are used for operational decision making such as inventory planning, ordering and scheduling of the workforce. Usually quantitative methods such as time series analysis are used in this time frame.

References

1. Wikipedia contributors. (2019). Forecasting. In Wikipedia, The Free Encyclopedia. Retrieved November 4, 2019, from https://en.Wikipedia.org/w/index.php...ldid=933732816 ↵
2. Saylor Academy. (2012). Principles of Marketing. Forecasting. Retrieved on November 4, 2019, from https://saylordotorg.github.io/text_...recasting.html ↵

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4.2: Qualitative Forecasting

Qualitative forecasting techniques are subjective, based on the opinion and judgment of consumers and experts; they are appropriate when past data are not available. They are usually applied to intermediate- or long-range decisions.

In the following, we discuss some examples of qualitative forecasting techniques:

Executive Judgement (Top Down)

Groups of high-level executives will often assume responsibility for the forecast. They will collaborate to examine market data and look at future trends for the business. Often, they will use statistical models as well as market experts to arrive at a forecast.

Sales Force Opinions (Bottom up)

The sales force in a business are those persons most close to the customers. Their opinions are of high value. Often the sales force personnel are asked to give their future projections for their area or territory. Once all of those are reviewed, they may be combined to form an overall forecast for district or region.

Delphi Method

This method was created by the Rand Corporation in the 1950s. A group of experts are recruited to participate in a forecast. The administrator of the forecast will send out a series of questionnaires and ask for inputs and justifications. These responses will be collated and sent out again to allow respondents to evaluate and adjust their answers. A key aspect of the Delphi method is that the responses are anonymous, respondents do not have any knowledge about what information has come from which sources. That permits all of the opinions to be given equal consideration. The set of questionnaires will go back and forth multiple times until a forecast is agreed upon.

Market Surveys

Some organizations will employ market research firms to solicit information from consumers regarding opinions on products and future purchasing plans.

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4.3: Quantitative Forecasting

Quantitative forecasting models are used to forecast future data as a function of past data. They are appropriate to use when past numerical data is available and when it is reasonable to assume that some of the patterns in the data are expected to continue into the future. These methods are usually applied to short- or intermediate-range decisions. Some examples of quantitative forecasting methods are causal (econometric) forecasting methods, last period demand (naïve), simple and weighted N-Period moving averages and simple exponential smoothing, which are categorizes as time-series methods. Quantitative forecasting models are often judged against each other by comparing their accuracy performance measures. Some of these measures include Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE).

We will elaborate on some of these forecasting methods and the accuracy measure in the following sections.[1]

References

1. Wikipedia contributors. (2019). Forecasting. In Wikipedia, The Free Encyclopedia. Retrieved on November 4, 2019, from https://en.Wikipedia.org/w/index.php...ldid=933732816 ↵

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4.4: Causal (Econometric) Forecasting Methods (Degree)

Some forecasting methods try to identify the underlying factors that might influence the variable that is being forecast. For example, including information about climate patterns might improve the ability of a model to predict umbrella sales. Forecasting models often take account of regular seasonal variations. In addition to climate, such variations can also be due to holidays and customs: for example, one might predict that sales of college football apparel will be higher during the football season than during the off-season.

Several informal methods used in causal forecasting do not rely solely on the output of mathematical algorithms, but instead use the judgment of the forecaster. Some forecasts take account of past relationships between variables: if one variable has, for example, been approximately linearly related to another for a long period of time, it may be appropriate to extrapolate such a relationship into the future, without necessarily understanding the reasons for the relationship.

One of the most famous causal models is **regression analysis**. In statistical modeling, regression analysis is a set of statistical processes for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables (or 'predictors'). More specifically, regression analysis helps one understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables is varied, while the other independent variables are held fixed.

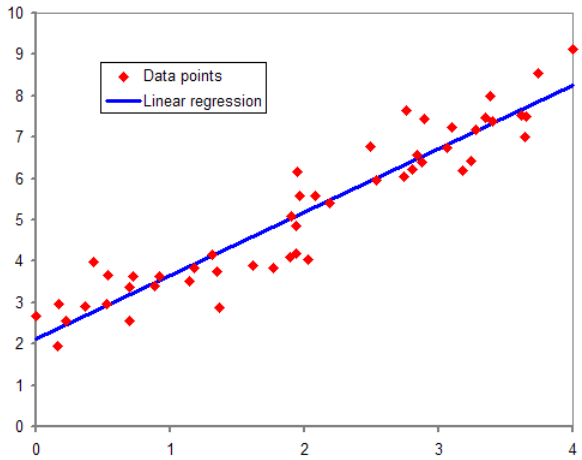

Figure 4.4.1: Example of regression analysis.

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4.5: Forecasting Assumptions and Demand Patterns

Common Forecasting Assumptions:

1. Forecasts are rarely, if ever, perfect. It is nearly impossible to 100% accurately estimate what the future will hold. Firms need to understand and expect some error in their forecasts.
2. Forecasts tend to be more accurate for groups of items than for individual items in the group. The popular Fitbit may be producing six different models. Each model may be offered in several different colours. Each of those colours may come in small, large and extra large. The forecast for each model will be far more accurate than the forecast for each specific end item.
3. Forecast accuracy will tend to decrease as the time horizon increases. The farther away the forecast is from the current date, the more uncertainty it will contain.

Demand Patterns

When we plot our historical product demand, the following patterns can often be found:

Trend – A trend is consistent upward or downward movement of the demand. This may be related to the product's life cycle.

Cycle – A cycle is a pattern in the data that tends to last more than one year in duration. Often, they are related to events such as interest rates, the political climate, consumer confidence or other market factors.

Seasonal – Many products have a seasonal pattern, generally predictable changes in demand that are recurring every year. Fashion products and sporting goods are heavily influenced by seasonality.

Irregular variations – Often demand can be influenced by an event or series of events that are not expected to be repeated in the future. Examples might include an extreme weather event, a strike at a college campus, or a power outage.

Random variations – Random variations are the unexplained variations in demand that remain after all other factors are considered. Often this is referred to as noise.

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4.6: Time Series Methods

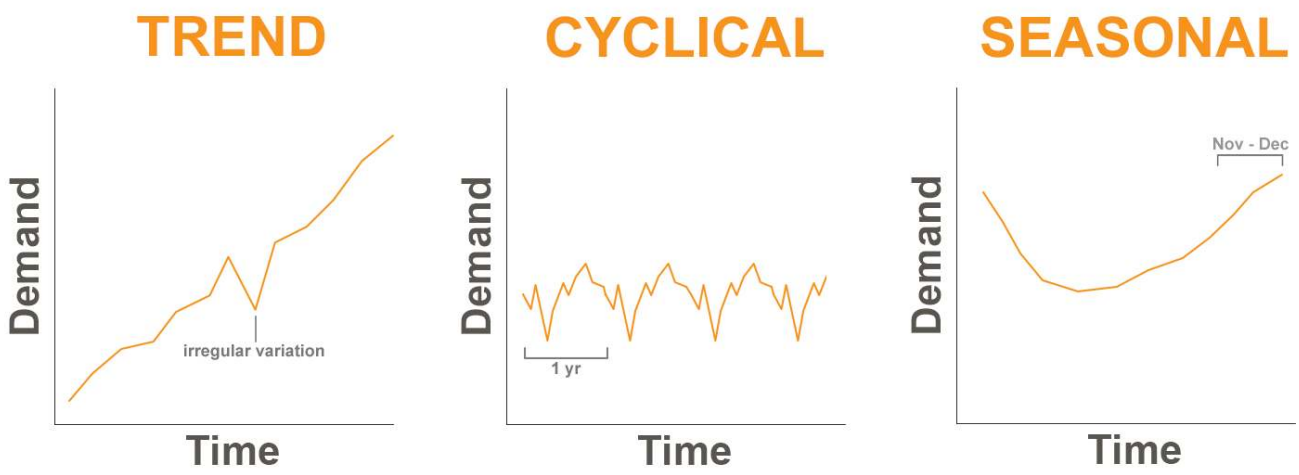

Figure 4.6.1: Diagram of trend, cyclical, and seasonal demand patterns.

Time series methods use historical data as the basis of estimating future outcomes. A time series is a series of data points indexed (or listed or graphed) in time order. Most commonly, a time series is a sequence taken at successive equally spaced points in time. Thus, it is a sequence of discrete-time data. Examples of time series are heights of ocean tides, counts of sunspots, and the daily closing value of the Dow Jones Industrial Average.

Time series are very frequently plotted via line charts. Time series are used in statistics, signal processing, pattern recognition, econometrics, mathematical finance, weather forecasting, earthquake prediction, electroencephalography, control engineering, astronomy, communications engineering, and largely in any domain of applied science and engineering which involves temporal measurements.[1]

In the following, we will elaborate more on some of the simpler time-series methods and go over some numerical examples.

Naïve Method

The simplest forecasting method is the naïve method. In this case, the forecast for the next period is set at the actual demand for the previous period. This method of forecasting may often be used as a benchmark in order to evaluate and compare other forecast methods.

Simple Moving Average

In this method, we take the average of the last “n” periods and use that as the forecast for the next period. The value of “n” can be defined by the management in order to achieve a more accurate forecast. For example, a manager may decide to use the demand values from the last four periods (i.e., n = 4) to calculate the 4-period moving average forecast for the next period.

Example 4.6.1

Some relevant notation:

D_t = Actual demand observed in period t

F_t = Forecast for period t

Using the following table, calculate the forecast for period 5 based on a 3-period moving average.

Period	Actual Demand
1	42
2	37
3	34
4	40

Solution

Forecast for period 5 = F5 = (D4 + D3 + D2) / 3 = (40 + 34 + 37) / 3 = 111 / 3 = 37

Weighted Moving Average

This method is the same as the simple moving average with the addition of a weight for each one of the last "n" periods. In practice, these weights need to be determined in a way to produce the most accurate forecast. Let's have a look at the same example, but this time, with weights:

Example 4.6.2

Period	Actual Demand	Weight
1	42	
2	37	0.2
3	34	0.3
4	40	0.5

Solution

Forecast for period 5 = F5 = (0.5 x D4 + 0.3 x D3 + 0.2 x D2) = (0.5 x 40+ 0.3 x 34 + 0.2 x 37) = 37.6

Note that if the sum of all the weights were not equal to 1, this number above had to be divided by the sum of all the weights to get the correct weighted moving average.

Exponential Smoothing

This method uses a combination of the last actual demand and the last forecast to produce the forecast for the next period. There are a number of advantages to using this method. It can often result in a more accurate forecast. It is an easy method that enables forecasts to quickly react to new trends or changes. A benefit to exponential smoothing is that it does not require a large amount of historical data. Exponential smoothing requires the use of a smoothing coefficient called Alpha (α). The Alpha that is chosen will determines how quickly the forecast responds to changes in demand. It is also referred to as the Smoothing Factor.

There are two versions of the same formula for calculating the exponential smoothing.

Here is version #1:

$F_t = (1 - \alpha) F_{t-1} + \alpha D_{t-1}$

Note that α is a coefficient between 0 and 1

For this method to work, we need to have the forecast for the previous period. This forecast is assumed to be obtained using the same exponential smoothing method. If there were no previous period forecast for any of the past periods, we will need to initiate this method of forecasting by making some assumptions. This is explained in the next example.

Example 4.6.3

Period	Actual Demand	Forecast
1	42	
2	37	
3	34	
4	40	
5		

Solution

In this example, period 5 is our next period for which we are looking for a forecast. In order to have that, we will need the forecast for the last period (i.e., period 4). But there is no forecast given for period 4. Thus, we will need to calculate the forecast for period 4 first. However, a similar issue exists for period 4, since we do not have the forecast for period 3. So, we need to go back for one more period and calculate the forecast for period 3. As you see, this will take us all the way back to period 1. Because there is no period before period 1, we will need to make some assumption for the forecast of period 1. One common assumption is to use the same demand of period 1 for its forecast. This will give us a forecast to start, and then, we can calculate the forecast for period 2 from there. Let's see how the calculations work out:

If $\alpha = 0.3$ (assume it is given here, but in practice, this value needs to be selected properly to produce the most accurate forecast)

Assume $F_1 = D_1$, which is equal to 42.

Then, calculate $F_2 = (1 - \alpha) F_1 + \alpha D_1 = (1 - 0.3) \times 42 + 0.3 \times 42 = 42$

Next, calculate $F_3 = (1 - \alpha) F_2 + \alpha D_2 = (1 - 0.3) \times 42 + 0.3 \times 37 = 40.5$

And similarly, $F_4 = (1 - \alpha) F_3 + \alpha D_3 = (1 - 0.3) \times 40.5 + 0.3 \times 34 = 38.55$

And finally, $F_5 = (1 - \alpha) F_4 + \alpha D_4 = (1 - 0.3) \times 38.55 + 0.3 \times 40 = 38.985$

Period	Actual Demand	Forecast
1	42	42 (assumed = D_1)
2	37	(1 – 0.3) x 42 + 0.3 x 42 = 42
3	34	(1 – 0.3) x 42 + 0.3 x 37 = 40.5
4	40	(1 – 0.3) x 40.5 + 0.3 x 34 = 38.55
5		(1 – 0.3) x 38.55 + 0.3 x 40 = 38.985

Figure 4.6.2: Solution for Exponential Smoothing Version 1

Accessible format for Figure 4.6.2

Here is version #2:

$F_t = F_{t-1} + \alpha(D_{t-1} - F_{t-1})$

Example 4.6.4

Assume you are given an alpha of 0.3, $F_{t-1} = 55$

Solution

Period	Actual Demand	Forecast
1	60	55 (assumed
2	55	55 + 0.3 x (60 – 55) = 56.5
3	51	56.5 + 0.3 x (55 – 56.5) = 56.05
4	58	56.05 + 0.3 x (51 – 56.05) = 54.53
5		54.54 + 0.3 x (58 – 54.53) = 55.64

Figure 4.6.3: Solution for Exponential Smoothing Version 2

Accessible format for Figure 4.6.3

Here is a video explaining moving averages using EXCEL.

https://www.linkedin.com/learning/search?keywords=moving%20averages&u=2169170

Here is a video explaining exponential smoothing using EXCEL.

https://www.linkedin.com/learning/search?keywords=exponential%20smoothing&u=2169170

Seasonal Index

Many organizations produce goods whose demand is related to the seasons, or changes in weather throughout the year. In these cases, a seasonal index may be used to assist in the calculation of a forecast.

Example 4.6.5

Season	Previous Sales	Average Sales	Seasonal Index
Winter	390	500	390 / 500 = .78
Spring	460	500	460 / 500 = .92
Summer	600	500	600 / 500 = 1.2
Fall	550	500	550 / 500 = 1.1
Total	2000		

Using these calculated indices, we can forecast the demand for next year based on the expected annual demand for the next year. Let's say a firm has estimated that next year annual demand will be 2500 units.

Solution

Season	Anticipated annual demand	Avg. Sales / Season (2500/4)	Seasonal Factor	New Forecast
Winter		625	0.78	.78 x 625 = 487.5
Spring		625	0.92	.92 x 625 = 575
Summer		625	1.2	1.2 x 625 = 750
Fall		625	1.1	1.1 x 625 = 687.5
Total	2500			

References

1. Wikipedia contributors. (2019). Time series. In *Wikipedia, The Free Encyclopedia*. Retrieved on November 4, 2019, from https://en.Wikipedia.org/w/index.php?title=Time_series&oldid=934671965↵

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4.7: Forecast Accuracy Measures

In this section, we will calculate forecast accuracy measures such as **Mean Absolute Deviation** (MAD), **Mean Squared Error** (MSE), and **Mean Absolute Percentage Error** (MAPE). We will explain the calculations using the next example.

Example 4.7.1

The following actual demand and forecast values are given for the past four periods. We want to calculate MAD, MSE and MAPE for this forecast to see how well it is doing.

Note that Abs (e_t) refers to the absolute value of the error in period t (e_t).

Period	Actual Demand	Forecast	e_t	Abs (et)	e_t^2	[Abs (e_t) / D_t] x 100%
1	63	68				
2	59	65				
3	54	61				
4	65	59				

Solution

Here are what need to do:

Step 1: Calculate the error as $e_t = D_t – F_t$ (the difference between the actual demand and the forecast) for any period t and enter the values in the table above.

Step 2: Calculate the absolute value of the errors calculated in step 1 [i.e., Abs (et)], and enter the values in the table above.

Step 3: Calculate the squared error (i.e., e_t^2) for each period and enter the values in the table above.

Step 4: Calculate [Abs (e_t) / D_t] x 100% for each period and enter the value under its column in the table above.

Period	Actual Demand	Forecast	e_t	Abs (et)	e_t^2	[Abs (e_t) / D_t] x 100%
1	63	68	-5	5	25	7.94%
2	59	65	-6	6	36	10.17%
3	54	61	-7	7	49	12.96%
4	65	59	6	6	36	9.23%

Calculations for Accuracy Measures:

MAD = The average of what we calculated in step 2 (i.e., the average of all the absolute error values)

= (5 + 6 + 7 + 6) / 4 = 24 / 4 = **6**

MSE = The average of what we calculated in step 3 (i.e., the average of all the squared error values)

= (25 + 36 + 49 + 36) / 4 = 146/4 = **36.5**

MAPE = The average of what we calculated in step 4

= (7.94% + 10.17% + 12.96% + 9.23%) / 4 = 40.3/4 = **10.075%**

Here is a video on Mean Absolute Deviation using EXCEL

https://www.linkedin.com/learning/search?keywords=mean%20absolute%20deviation%20&u=2169170

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4.8: End of Chapter Problems

Problem #1

Below are monthly sales of light bulbs from the lighting store.

Month	Sales
Jan	255
Feb	298
Mar	357
Apr	319
May	360
June	

Forecast sales for June using the following

1. Naïve method
2. Three- month simple moving average
3. Three-month weighted moving average using weights of .5, .3 and .2
4. Exponential smoothing using an alpha of .2 and a May forecast of 350.

Solution

1. 360
2. (357 + 319 + 360) / 3 = 345.3
3. 360 x .5 + 319 x .3 + 357 x .2 = 347.1
4. 350 + .2(360 – 350) = 352

Problem #2

Demand for aqua fit classes at a large Community Center are as follows for the first six weeks of this year.

Week	Demand
1	162
2	158
3	138
4	190
5	182
6	177
7	

You have been asked to experiment with several forecasting methods. Calculate the following values:

1. a) Forecast for weeks 3 through week 7 using a two-period simple moving average
2. b) Forecast for weeks 4 through week 7 using a three-period weighted moving average with weights of .6, .3 and .1

3. c) Forecast for weeks 4 through week 7 using exponential smoothing. Begin with a week 3 forecast of 130 and use an alpha of .3

Solution

Week	Demand	a)	b)	c)
1	162			
2	158			
3	138	(162 + 158) / 2 = **160**		**130**
4	190	(158 + 138) / 2 = **148**	138 x .6 + 158 x .3 + 162 x .1 = **146.4**	130 + .3 x (138 – 130) = **132.4**
5	182	(138 + 190) / 2 = **164**	190 x .6 + 138 x .3 + 158 x .1 = **171.2**	132.4 + .3 x (190 – 132.4) = **149.7**
6	177	(190 + 182) / 2 = **186**	182 x .6 + 190 x .3 + 138 x .1 = **180**	149.7 + .3 x (182 – 149.7) = **159.4**
7		(182 + 177) / 2 = **179.5**	177 x .6 + 182 x .3 + 190 x .1 = **179.8**	159.4 + .3 x (177 – 159.4) = **164.7**

Problem #3

Sales of a new shed has grown steadily from the large farm supply store. Below are the sales from the past five years. Forecast the sales for 2018 and 2019 using exponential smoothing with an alpha of .4. In 2015, the forecast was 360. Calculate a forecast for 2016 through to 2020.

Year	Sales	Forecast
2015	348	360
2016	372	
2017	311	
2018	371	
2019	365	
2020		

Solution

Year	Sales	Forecast
2015	348	**360**
2016	372	360 + .4 x (348 – 360) = **355.2**
2017	311	355.2 + .4 x (372 – 355.2) = **361.9**
2018	371	361.9 + .4 x (311 – 361.9) = **341.6**
2019	365	341.6 + .4 x (371 – 341.6) = **353.3**
2020		353.3 + .4 x (365-353.3) = **358.0**

Problem #4

Below is the actual demand for X-rays at a medical clinic. Two methods of forecasting were used. Calculate a mean absolute deviation for each forecast method. Which one is more accurate?

Week	Actual Demand	Forecast #1	Forecast #2
1	48	50	50
2	65	55	56
3	58	60	55
4	79	70	85

Solution

Week	Actual Demand	Forecast #1	IerrorI	Forecast #2	IerrorI
1	48	50	2	50	2
2	65	55	10	56	9
3	58	60	2	55	3
4	79	70	9	85	6
		Mean Abs Deviation:	**5.75**	**Mean Abs Deviation:**	**5**

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CHAPTER OVERVIEW

5: Strategic Capacity Planning

Learning Objectives

- What are common capacity strategies?
- Calculate efficiency and utilization measures.
- Describe factors that determine effective capacity.
- Understand the steps in the capacity planning process.
- Determine the capacity in a sequential process with a bottleneck.
- Use break even analysis to evaluate capacity alternatives.

This module examines how important strategic capacity planning is for products and services. The overall objective of strategic capacity planning is to reach an optimal level where production capabilities meet demand.

5.1: Introduction to Strategic Capacity Planning
5.2: Capacity Planning for Products and Services
5.3: Defining and Measuring Capacity
5.4: Determinants of Effective Capacity
5.5: The Sequential Processes and the Bottleneck
5.6: Evaluating Capacity Alternatives

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5.1: Introduction to Strategic Capacity Planning

This module examines how important strategic capacity planning is for products and services. The overall objective of strategic capacity planning is to reach an optimal level where production capabilities meet demand. Capacity needs include equipment, space, and employee skills. If production capabilities are not meeting demand, it will result in higher costs, strains on resources, and possible customer loss. It is important to note that capacity planning has many long-term concerns given the long-term commitment of resources.

Managers should recognize the broader effects capacity decisions have on the entire organization. Common strategies include **leading capacity**, where capacity is increased to meet expected demand, and **following capacity**, where companies wait for demand increases before expanding capabilities. A third approach is **tracking capacity**, which adds incremental capacity over time to meet demand.

Finally, the two most useful functions of capacity planning are design capacity and effective capacity. **Design capacity** refers to the maximum designed capacity or output rate and the **effective capacity** is the design capacity minus personal and other allowances. These two functions of capacity can be used to find the efficiency and utilization. These are calculated by the formulas below:

$$\begin{gathered}\text{Efficiency} = (\text{Actual Output / Effective Capacity}) \text{ x } 100\% \\ \text{Utilization} = (\text{Actual Output / Design Capacity}) \times 100\% \\ \text{Effective Capacity} = \text{Design Capacity - allowances}\end{gathered} \tag{5.1.1}$$

Example 5.1.1

Actual production last week = 25,000 units

Effective capacity = 28,000 units

Design capacity = 230 units per hour

Factory operates 7 days / week, three 8-hour shifts

1. What is the design capacity for one week?
2. Calculate the efficiency and utilization rates.

Solution

(Using the formulas above)

1. Design capacity = (7 x 3 x 8) x (230) = 38,640 units per week
2. Utilization = 25,000 / 38,640 = 64.7%
   Efficiency = 25,000 / 28,000 = 89.3%

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5.2: Capacity Planning for Products and Services

Capacity refers to a system's potential for producing goods or delivering services over a specified time interval. Capacity planning involves long-term and short- term considerations. Long-term considerations relate to the overall level of capacity; short-term considerations relate to variations in capacity requirements due to seasonal, random, and irregular fluctuations in demand.

Excess capacity arises when actual production is less than what is achievable or optimal for a firm. This often means that the demand in the market for the product is below what the firm could potentially supply to the market. Excess capacity is inefficient and will cause manufacturers to incur extra costs. Capacity can be broken down in two categories: Design Capacity and Effective Capacity.

Three key inputs to capacity planning are:

1. The kind of capacity that will be needed
2. How much capacity will be needed?
3. When will it be needed?

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5.3: Defining and Measuring Capacity

When selecting a measure of capacity, it is best to choose one that doesn't need updating. For example, dollar amounts are often a poor measure of capacity (e.g., a restaurant may have capacity of $1 million of sales a year) because price changes over time necessitate updating of that measure.

When dealing with more than one product, it is best to measure capacity in terms of each product. For example, the capacity of a firm is to either produce 100 microwaves or 75 refrigerators. This is less confusing than just saying the capacity is 100 or 75. Another method of measuring capacity is by referring to the availability of inputs. This is usually more helpful if we are dealing with several type of output. Note that one specific measure of capacity can't be used in all situations; it needs to be tailored to the specific situation at hand. The following table shows examples of both output and input used for capacity measures.

Table 5.3.1: Various businesses and their respective input and output measures of capacity.

Type of Business	Input Measures of Capacity	Output Measures of Capacity
Car manufacturer	Labour hours	Cars per shift
Hospital	Available beds	Patients per month
Pizza parlour	Labour hours	Pizzas per day
Retail store	Floor space (sq. ft.)	Revenue per sq. ft.

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5.4: Determinants of Effective Capacity

- **Facilities:** The size and provision for expansion are key in the design of facilities. Other facility factors include locational factors, such as transportation costs, distance to market, labor supply, and energy sources. The layout of the work area can determine how smoothly work can be performed.
- **Product and Service Factors:** The more uniform the output, the more opportunities there are for standardization of methods and materials . This leads to greater capacity.
- **Process Factors:** Quantity capability is an important determinant of capacity, but so is output quality. If the quality does not meet standards, then output rate decreases because of need of inspection and rework activities. Process improvements that increase quality and productivity can result in increased capacity. Another process factor to consider is the time it takes to change over equipment settings for different products or services.
- **Human Factors:** the tasks that are needed in certain jobs, the array of activities involved, and the training, skill, and experience required to perform a job all affect the potential and actual output. Employee motivation, absenteeism, and labour turnover all affect the output rate as well.
- **Policy Factors:** Management policy can affect capacity by allowing or disallowing capacity options such as overtime or second or third shifts
- **Operational Factors:** Scheduling problems may occur when an organization has differences in equipment capabilities among different pieces of equipment or differences in job requirements. Other areas of impact on effective capacity include inventory stocking decisions, late deliveries, purchasing requirements, acceptability of purchased materials and parts, and quality inspection and control procedures.
- **Supply Chain Factors:** Questions include: What impact will the changes have on suppliers, warehousing, transportation, and distributors? If capacity will be increased, will these elements of the supply chain be able to handle the increase? If capacity is to be decreased, what impact will the loss of business have on these elements of the supply chain?
- **External Factors:** Minimum quality and performance standards can restrict management's options for increasing and using capacity

Summary of examples of capacity factors.

Facility Factors

- e.g. expansion potential, strategic location

Product & Service Factors

- e.g. uniformity within the product manufactured or service executed

Process Factors

- e.g. reducing inspections, efficient equipment adjustments

Human Factors

- e.g. high employee motivation, low absenteeism, low labour turnover

Policy Factors

- e.g. opportunity for overtime and/or additional shifts

Operational Factors

- e.g. well-stocked inventory, minimal scheduling delays

Supply Chain Factors

- e.g. adaptable distributors

External Factors

- e.g. minimal interference with quality and performance standards

Inadequate planning can be a major limitation in determining the effective capacity.

The most important parts of effective capacity are process and human factors. Process factors must be efficient and must operate smoothly. If not, the rate of output will dramatically decrease. They must be motivated and have a low absenteeism and labour turnover. In resolving constraint issues, all possible alternative solutions must be evaluated.

Steps in the Capacity Planning Process:

1. Estimate future capacity requirements
2. Evaluate existing capacity and facilities and identify gaps
3. Identify alternatives for meeting requirements
4. Conduct financial analyses of each alternative
5. Assess key qualitative issues for each alternative
6. Select the alternative to pursue that will be best in the long term
7. Implement the selected alternative
8. Monitor results

The above content is an adaptation of Saylor Academy's BUS300 course.[1]

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5.5: The Sequential Processes and the Bottleneck

Any process that has several steps, one after another, is considered a **sequential process**. A good example of these processes is the manufacturing assembly line in which each workstation gets inputs from a previous workstation and give its outputs to the next workstation. It is safe to assume that each step has its own staff member, since this is exactly what happens in assembly lines. For this kind of process, it is crucial to have a balanced time across all steps. That is, there should not be any big difference between the amounts of time that different steps take to process one unit of product. For example, if step 1, 2 and 3 take 3, 10 and 5 minutes consecutively to process one unit of product, two main issues will happen during the production:

1) There will be a big pile of inventory sitting right before step 2, since step 1 is much faster than step 2, and the products that are already processed in step 1 will need to wait for step 2 to be done with its current unit at hand. As a result, this becomes an inventory holding issue, which is costly.

2) Step 3 will always need to wait for step 2 for an extra 5 minutes. This is due to the fact that step 3 finished its current product at hand in 5 minutes, but step 2 needs a total of 10 minutes to finish its work and feed it to step 3. This causes step 3 to be idle for a long time, which is also costly for the company. This is costly, because the company is already paying the staff who works in step 3 for the whole time, but they are not able to produce as many units as they should due to the very slow entry of the inputs coming from step 2.

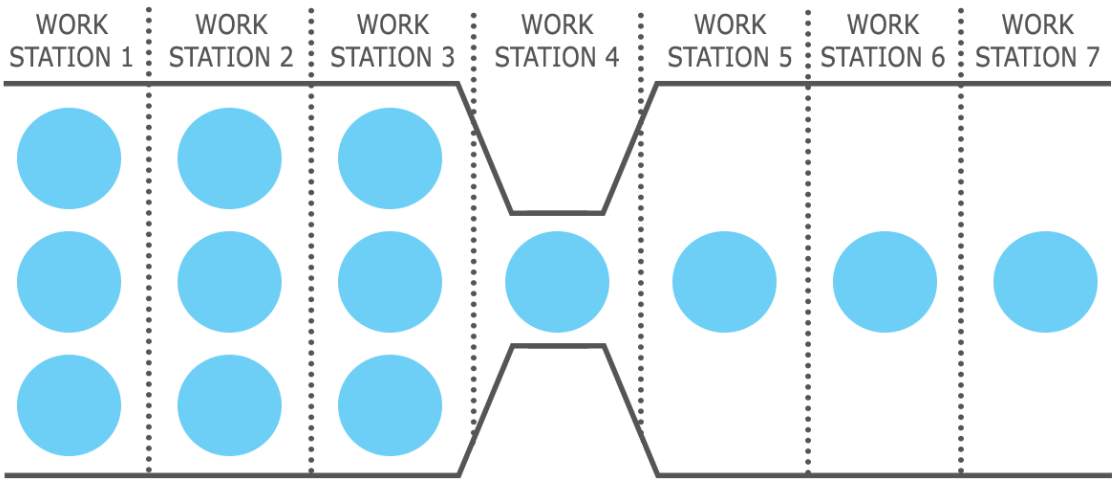

Figure 5.5.1: A diagram displaying the effects of a bottleneck.

The bottleneck is the slowest step in each process or the slowest process in a system. The capacity of the bottleneck defines the capacity of the whole process. In our example above, step 2 was the slowest, and as a result, the bottleneck. This means that the whole process (including all steps 1 to 3) will not be able to have an output any faster than one every 10 minutes. In the following, let's see why this is happening:

In an 8-hour shift per day, we have 8 x 60 = 480 minutes

Assuming that step 1 has enough input to process during the day, the total output from step 1 will be 480 / 3 = 160 units per day. This is the capacity for step 1. In a similar way, the capacity for step 2 is 480 / 10 = 48, and the capacity for step 3 is 480 / 5 = 96 units.

This means that the input to step 2 will be 160 units to be processed. But as we see, step 2 will only be able to process a maximum of 48 units per day. That means that only 48 units get to step 3 for processing. Since step 3 has a capacity of 96 units per day, it will easily process those 48 units of inputs, and the output from step 3 will be 48 units. Because the step 3 is the last step of our process, this output of 48 units will automatically be the total output of the whole process per day.

The key observation here is that the capacity of step 2, which is the bottleneck, determined the capacity of the whole process. This concept is very important in practice. Often times, the companies that do not pay attention to the concept of bottleneck and its

implications invest in parts of the process that are not bottleneck. This will keep the bottleneck unchanged and as a result, they will not see any improvement in the capacity of the whole process.

Example 5.5.1

Caroline has a thriving business selling her tote bags through several popular websites. Her business volume has caused her to hire full-time employees. Her business has four main manufacturing operations: 1) cutting fabric (4 min), 2) stitching fabric (7 min), 3) adding zippers, toggles, and liner (10 min), and 4) inspecting, packing, and labeling (5 min).

Figure 5.5.2: Flow diagram depicting the time taken for each step of Caroline's manufacturing process.

Employees work 7 hours per day. Help Caroline to determine the following:

1. Based on her very high demand, is there a bottleneck and what stage is it? What is the capacity of the process per day?
2. Caroline's employee at step #2 has found a new machine that will enable him to do the stitching faster, at a rate of 5 min per bag instead of 7 min. The machine costs $3500. Would you suggest this is a good investment to help Caroline increase her output? Why or why not?
3. If there were another person to be added to the process, where should Caroline add him or her and what would be the new capacity?

Solution

5.5.1: Solution for Caroline's Totes example

Operation	Time	Daily Capacity
Step 1: Cutting fabric	4 min	420 / 4=105
Step 2: Stitching fabric	7 min	420 / 7=60
Step 3: Adding zippers, toggles, liners	10 min	420 / 10=42
Step 4: Inspecting, packing, labeling	5 min	420 / 5=84

(Based on 7×60 = 420 min per day)

1. The maximum output is 42 units, because that is what the bottleneck can do. The bottleneck is at stage #3, which is the slowest part of the process.
2. Caroline should NOT invest any funds into step #2. This may speed up the stitching, but the maximum output of the process will still be 42 units because step #3 has not changed.
3. If Caroline added another person, she should add it to step #3. (Install zippers/ toggles/ liner). Because that is where the bottleneck is. The capacity at stage three would now double to 84 units per day. The new capacity for the whole process would now be 60 units per day, as determined by Step 2 (Basic stitching) which is the new bottleneck of the process.

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5.6: Evaluating Capacity Alternatives

There are two major ways to evaluate the capacity alternatives to select the best one: economic and non-economic.

Economic considerations take into account the cost, useful life, compatibility and revenue for each alternative. Techniques used for evaluation are:

- Break Even Analysis (this is the only one discussed in this chapter)
- Payback Period
- Net Present Value

Non-economic considerations include public opinion, reactions from employees and community pressure.

Break Even Analysis

Basically, since there is usually a fixed cost (FC) associated with the usage of a capacity, we look for the right quantity of output that gives us enough total revenue (TR) to cover for the total cost (TC) that we have to incur. This quantity is called Break-Even Point (BEP), Break-Even Quantity (Q_{BEP}).

Total cost is the summation of the fixed cost and the total variable cost (VC, which depends on the quantity of output). In other words, at Q_{BEP}, we have: TC = FC + VC

A list of relevant notation can be found below:

$$
\begin{gathered}
TC = \text{total cost} \\
FC = \text{total fixed cost} \\
VC = \text{total variable cost} \\
TR = \text{total revenue} \\
v = \text{variable cost per unit} \\
R = \text{revenue per unit} \\
Q = \text{volume of output} \\
Q_{BEP} = \text{break even volume} \\
P = \text{profit}
\end{gathered}
$$

Fixed cost is regardless of the quantity of output. Some examples of fixed costs are rental costs, property taxes, equipment costs, heating and cooling expenses, and certain administrative costs

With the above notation and some simplification in the calculation, we have:

$$
\begin{aligned}
&TC = FC + VC \\
&VC = Q \times v \\
&TR = Q \times r \\
&P = TR - TC = Q \times r - (FC + Q \times v) \\
&Q_{BEP} = FC/(r - v)
\end{aligned}
\tag{5.6.1}
$$

Example 5.6.1

The management of a pizza place would like to add a new line of small pizza, which will require leasing a new equipment for a monthly payment of $4,000. Variable costs would be $4 per pizza, and pizzas would retail for $9 each.

1. How many pizzas must be sold per month in order to break even?
2. What would the profit (loss) be if 1200 pizzas are made and sold in a month?
3. How many pizzas must be sold to realize a profit of $10,000 per month?
4. If demand is expected to be 700 pizzas per month, will this be a profitable investment?

Solution

1. $Q_{BEP} = FC / (r - v)$ = 4000 / (9 – 4) = 800 pizzas per month
2. total revenue – total cost = 1200 x 9 – 1200 x 4 = $6000 (i.e. a profit)

3. $P = \$10000 = Q(r - v) - FC$;
   Solving for Q will give us: $Q = (10000 + 4000) / (9 - 4) = 2800$
4. Producing less than 800 (i.e. Q_{BEP}) pizzas will bring in a loss. Since 700 < 800 (Q_{BEP}), it is not a profitable investment.

Finding a break-even point between "make" or "buy" decisions:

Question: For what quantities would buying the product be preferred to making it in-house? For quantities larger than the break-even quantity or for smaller ones?

v_m = per unit variable cost of "make"
v_b = per unit variable cost of "buy"

total cost of "make" = total cost of "buy"
$= Q \text{ x } v_m + FC = Q \text{ x } v_b$
$= FC = Q \text{ x } v_b - Q \text{ x } \mathrm{v_m}$
$= Q = FC / (v_b - v_m)$

Example 5.6.2

The ABX Company has developed a new product and is wondering if they should make this product in-house or have a capable supplier make the product for them. The costs associated with each option are provided in the following table:

Product Development	Fixed Cost (annual)	Variable Cost
Make in-house	$160,000	$100
Buy		$150

1. What is the break-even quantity at which the company will be indifferent between the two options?
2. If the annual demand for the new product is estimated at 1000 units, should the company make or buy the product?
3. For what range of demand volume it will be better to make the product in-house?

Solution

Solution

1. $Q_{BEP} = FC / (v_b - v_m) = 160{,}000 / (150 - 100) = 3200$
2. Total cost of "make" = 1000 x 100 + 160,000 = $260,000; Total cost of "buy" = 1000 x 150 = $150,000
   Thus, it will be better to buy since it will be less costly in total.
3. It will always be better to use the option with the lower variable cost for quantities greater than the break-even quantity.
   This can also be proven as follows:

We want "make" to be better than "buy" in this part of the question. Thus, for any quantity Q, we need to have:

Total cost of "make" < Total cost of "buy"
$= 160{,}000 + 100Q < 150Q$
$= 160{,}000 < 50Q$
$= 3200 < Q$

Finding a break-even point between two make decisions

Question: For what quantities would machine A be preferred to machine B? For quantities larger that the break-even quantity or for smaller ones?

If we assume the two options for making a product are machine A, with a fixed cost of FC_A and a variable cost of v_A, and machine B, with a fixed cost of FC_B and a variable cost of v_B, we have:

total cost of A = total cost of B
= Q x $v_A + FC_A = Q$ x $V_B + FC_B$
= $FC_A - FC_B = Q$ x $V_B - Q$ x V_A
= $Q = (FC_A - FC_B) / (V_B - V_A)$

In any problem, it is suggested that you write down the total cost of each option and simplify from there to make sure that you do not miss any possible additional cost factors (if any).

Example 5.6.3

The ABX Company has developed a new product and is going to make this product in-house. To be able to do this, they need to get a new equipment to be able to do the special type of processing required by the new product design. They have found two suppliers that sell such equipment. They are wondering which supplier they go ahead with. The costs associated with each option are provide in the following table:

Suppliers	Fixed Cost (annual)	Variable Cost
Supplier A	$160,000	$150
Supplier B	$200,000	$100

1. What is the break-even quantity at which the company will be indifferent between the two options?
2. If the annual demand for the new product is estimated at 1000 units, which supplier should the company use?
3. For what range of demand volume each supplier will be better?

Solution

1. $Q_{BEP} = (FC_B - FC_A) / (v_A - v_B)$ = (200,000 – 160,000) / (150 – 100) = 40,000/50 = 800
2. Total cost of Supplier A = 1000 x 150 + 160,000 = $310,000; Total cost of Supplier B = 1000 x 100 + 200,000 = $300,000
   Thus, it will be better to go with Supplier B, since it will be less costly in total.
3. It will always be better to use the option with the lower variable cost for quantities greater than the break-even quantity. This can also be proven as follows:

Let's see for what quantities Supplier B will be better than Supplier A. In that case, for the quantity Q, we need to have:

Total cost of Supplier B < Total cost of Supplier A
= 200,000 + 100Q < 160,000 + 150Q
= 40,000 < 50Q
= 800 < Q

This means that for quantities above 800 units, Supplier B will be cheaper in total. Thus, for quantities less than 800, Supplier A will be cheaper in total.

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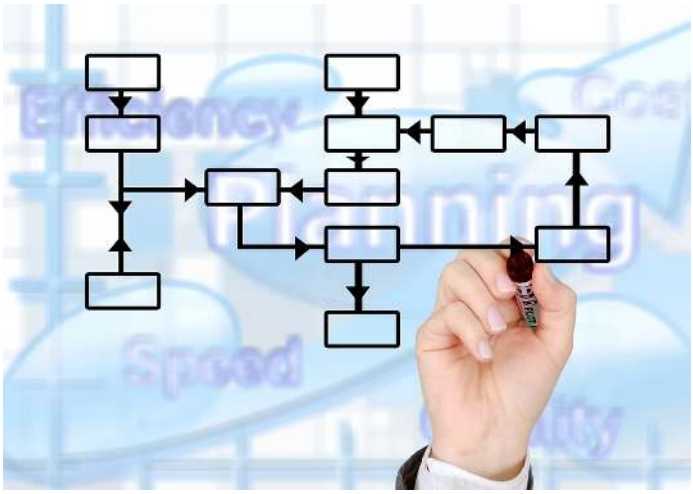
CHAPTER OVERVIEW

6: Process Design



Learning Objectives

- Differentiate between the different types of processes.
- Understand common layouts and their challenges.
- Calculate takt time based on product demand.

6.1: Introduction to Process Design
6.2: Make-to-order and Make-to-stock
6.3: Process Types
6.4: Facility Layout
6.5: Some important “Times” to be familiar with-
6.6: Process Flowcharting

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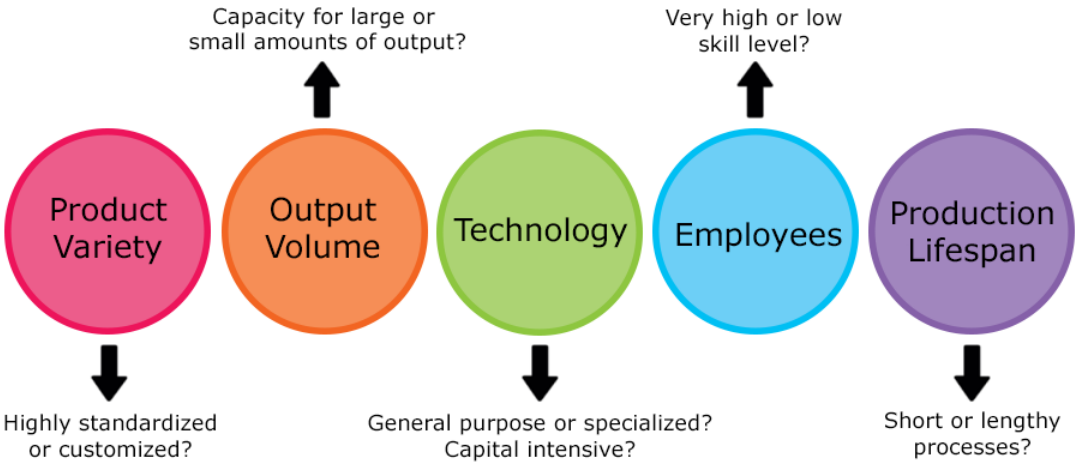
6.1: Introduction to Process Design

Every firm that produces a good or a service will do so by the use of a process. This process will use the firm's resources in order to transform the primary inputs into some type of output. In designing the actual process, particularly the number and sequence of steps, several important factors need to be considered.

1. Product variety – Is the product highly standardized, or is the product highly customized?
2. Volume of output – Is the business created to produce large volumes or a small amount of output?
3. Is the technology to be used general purpose or specialized? Is it capital intensive?
4. The skill level of employees, it is very high or low?
5. What is the expected duration?



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6.2: Make-to-order and Make-to-stock

It is useful to categorize processes as either make-to-order or make-to-stock.

In a **make-to-order** business, the customer's order is not manufactured until the order is received. This allows customization to the exact specifications that the customer requires. It may also be referred to as build-to-order. This type of production is considered a pull type system. The work is "pulled" through the process when customer demand is present.

The disadvantage of this type of system is that it takes time for the firm to acquire any materials and needed components, and then to schedule and produce the customers order. Goods are made in small amounts, and may be more expensive.

The advantage of this type of process is that inventory is lower than in a typical make-to-stock system. There is not any uncertainty about what the customer desires and there is no obsolete stock to be disposed of. Dell Computer has utilized this type of system to produce personal computers very successfully.

In a **make-to-stock** process, goods are produced in anticipation of customer demand, usually from a sales forecast. These products are generally made in larger amounts and put into storage to wait for customer orders. Although the unit cost may be lower due to large production volumes, there may be losses due to forecast error, excess inventory, obsolescence and theft. Lead times however are short because goods are available when the customer places the order. These goods are not customized, but standardized

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6.3: Process Types

Process Types include

- Project
- Job Shop
- Batch
- Repetitive
- Continuous
- Hybrids

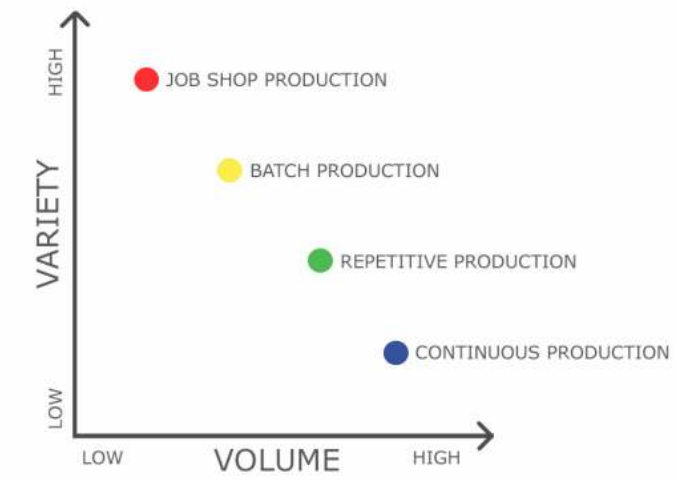

Figure 6.3.1: Process types depend on the variety and volume of production

Project

A one-time event, such as construction of an apartment building, implementation of a new ERP system, or writing a book, would all be considered a project type of process. Each of these projects have a high degree of customization, substantial use of resources, and a complex set of related activities. There is only a single output at the end of the project.

Job Shop

Many businesses have a job shop type of process. This is most commonly used when the product being produced is unique for each customer. It is a make-to-order type of business where production is intermittent (i.e. rather than one entire product being completed at a time, work will continue on multiple products as time permits). Often the product has unique characteristics for each customer. The workers in this type of business are very highly skilled in their craft or trade. Often they are referred to as craftsmen or makers. The volume of output is low in a job shop. The equipment used is quite general purpose. Examples include a small bakery that produces beautiful custom wedding cakes, or a business that makes custom guitars or bicycles based on the customers measurements and preferences of materials and components.

Batch

Some businesses are in the situation where they make groups of identical products on a regular basis. These groups are referred to as a batch. The batch will progress through a set of steps to be completed from the start to the end. An organization may have multiple batches at different stages coming through the process. This type of processing is also intermittent. (start, stop, start) There

is less variety in this type of business (compared to a job shop) and the equipment used will be relatively general purpose and suited to the industry that they are in. Employees need to be skilled and experienced at operating that equipment and producing these products. Examples of products made using batch production are baked goods, aircraft parts, clothing, and vaccines. An important decision by these firms is how big the batch should be.

Repetitive

This type of business produces products that are more standardized in nature. Usually the output is high. Since the goods are quite standardized, the equipment used tends to be quite specialized and often highly customized for that process. The skill level of the employees is usually low because the steps are highly standardized. Although these types of jobs may not require a trade or extensive experience, they often do require skills such as multi-tasking, concentration, problem solving, and teamwork. Often, these processes use flexible automation that allows for customization such as the addition of upgraded features. Examples of a repetitive process include assembly lines such as assembling automobiles or electronics, a carwash, or a cafeteria line.

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Continuous

A continuous process is when a very high volume of standardized product is produced. The type of product being made is described as non-discrete. This means that these businesses do not produce individual products, rather a product that is often a liquid or a product such as sugar, gasoline, or steel. An example of this type of process is an oil refinery. There are not separate individual workstations, rather the product flows from one step to the next within the system. The equipment in this type of process is highly complex and designed solely for that product at that facility. There are very few workers except for those that are responsible for process monitoring, maintenance, and cleaning.

Hybrids

There are many firms using mixtures of process types. One such common exception is the **Mass Customization**model of production. In mass customization, a company combines low-cost high volume of output, but each and every customer order is customized to the customers specifications. Usually the use of computer-aided manufacturing systems is what permits this customization. Examples include furniture makers who wait to produce the exact model of sofa based on the customers dimensions and fabric choice, or the vehicle manufacturer that has dozens of customization packages and paint options such that each vehicle is custom for the purchaser. A key requirement for successful mass customization is a modular design to allow fast seamless change from each product to the next.

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6.4: Facility Layout

Layout refers to the way in which organizations position their equipment, departments, or workcentres. Having an effective layout can streamline production activities, eliminate wasted or redundant movement and improve safety. The general types of layouts are: a fixed position layout, a process layout (functional), a product (line) layout, and a cellular layout, which is considered a hybrid. Other common layouts include office layouts, retail layouts, and warehouse layout.

Fixed Position Layout

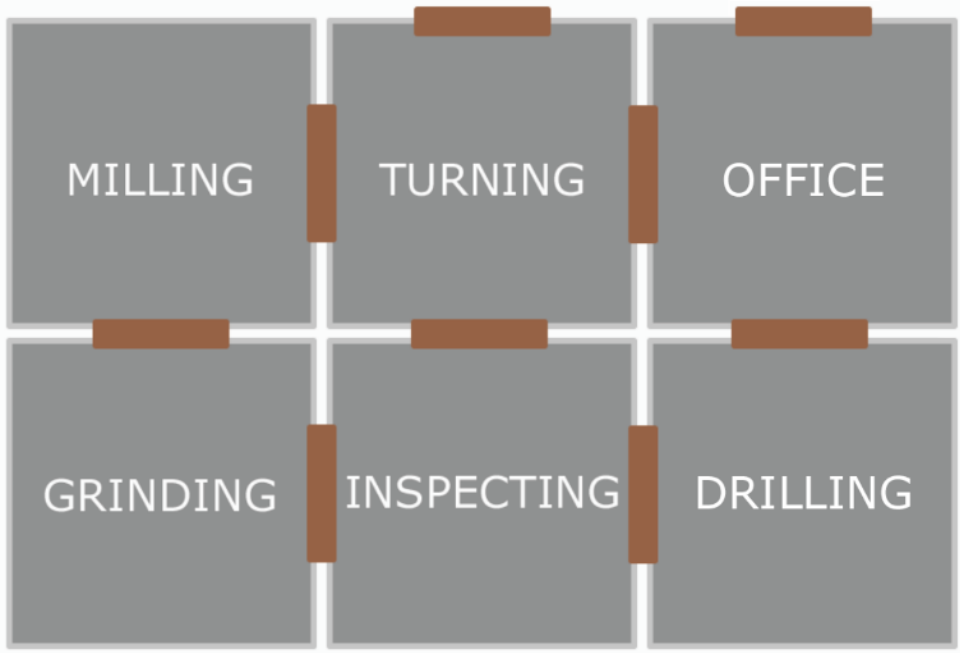
When producing a product that is not easily able to be moved, it may require that the worker, their tools and equipment are brought to the site where the production is taking place. This is a common layout in manufacturing a building, a ship or performing repairs to major equipment.

A process layout is a layout in which departments, equipment, or workcentres are arranged according to their function. In a manufacturing environment, all of the milling machines may be in one area or "department," the lathes may be in another area, and the drilling machines all in another area. This layout is also common in services. In a department store, similar goods are arranged together such as footwear, jewelry, and housewares. At a hospital, cardiology is in one area, maternity in another location, and pediatrics elsewhere. The specific dedicated equipment and skilled practitioners work in each of these areas.

An advantage to a process layout is that equipment tends to be quite general-purpose. If one particular piece of equipment breaks down, it will not halt the entire process. This type of process gives flexibility to handle a variety of products or customers. It is ideal for job shops or small batch manufacturing.

A disadvantage of a process layout is that a particular product will likely have to travel from department to department to get the set of processes completed. This often leads to lots of material handling and movement of goods throughout the facility. A flexible material-handling system is needed such as forklifts. Inventory will sit in each area waiting for its turn to be processed. This waiting inventory is referred to as **queue.** When examining the total throughput time of jobs through the system, it is often discovered that each order spends much more time waiting in queue than it does actually being processed. For that reason, this type of layout is generally very inefficient. A major consideration in a process layout is to ensure that departments with a large amount of interaction are located nearby one another.

Below is an example of a machinery plant with a process layout:



Product (Line) Layout

These are used in businesses that use assembly lines or production lines. If the product has high volume an assembly line might be the best option. The equipment in these types of layouts are often very capital intensive and are laid out according to the progressive steps of the process. Each work station is located along the line and may consist of a worker with equipment, or robots. Often each work station is adding components (assembly line) or modifying a product (production line). It is important to note that it is not necessarily a straight line, often assembly lines zig zag or are in a shape to use the maximum amount of space available. Some services may use a line layout, such as preparing hospital meals, or a cafeteria line. Due to considerable cost involved with setting up an assembly line, a large volume of product needs to be produced. Demand that is steady and consistent is ideal.

The goods produced in a line layout are generally very standardized, and the work processes are also highly standardized. Each product follows the same set of steps so that a fixed path material handling system is used such as a conveyor belt. This conveyor belt may be manual or automatic. It may operate at a pre determined speed, or it may be worker paced. It may run continuously or pulsed. The speed of the conveyor will determine the amount of product that will be produced per shift.

In contrast to a process layout a product layout is very efficient**.** There are a number of reasons for this.

1. Because of the division of labour and the repetition, there is less variability in the work performed
2. There is no build up of inventory, and no waiting. When completed at one work station, the job automatically moves to the next workstation. Only the inventory that is in process is in the system. Goods tend to be shipped when they are completed.
3. Due to the material handling system, goods move quickly and not very far.
4. Changeovers are not necessary so very little time is lost in changing between products.

It is important that assembly lines are balanced**.** The amount of time required at a preceding work station should be relatively similar to the amount of time required at the following work station.

Challenges in a product (line) layout include:

1. The fact that the line may be susceptible to shut downs if there are equipment malfunctions so preventative maintenance is critical. Preventative maintenance involves the inspection and replacement of any parts that have a high probability of failures, as well as holding ample spare parts in stock and having a detailed maintenance schedule for each piece of equipment.
2. Training and job rotation are critical activities to make sure employees are capable of completing the work tasks and that there are multiple people that can work at each individual job
3. With repetitive standardized jobs, it is critical that good ergonomic job design is performed. Organizations that ensure the health, safety and comfort of their employees reap rewards in terms of the quality of work they receive from employees.

Cellular Layout

Cellular layouts are considered a “hybrid” type of layout because it includes characteristics of both a Process layout and a product (line) layout. It is very common that a business may have multiple product lines, with far too much variety in order to take advantage of one assembly line. Often these businesses may have been using a process layout, with all of the associated product movement and waiting times. An alternative that became popular beginning in the late 1980s is the Cellular layout type. This type of production layout is still heavily utilized today.

This type of layout begins with the company performing a thorough analysis of their products and deciding which products are similar to one another and often share common geometry and processing requirements in terms of equipment, machinery, technology and employee skills. These products are grouped together and manufactured in a work cell. This is referred to as group technology.

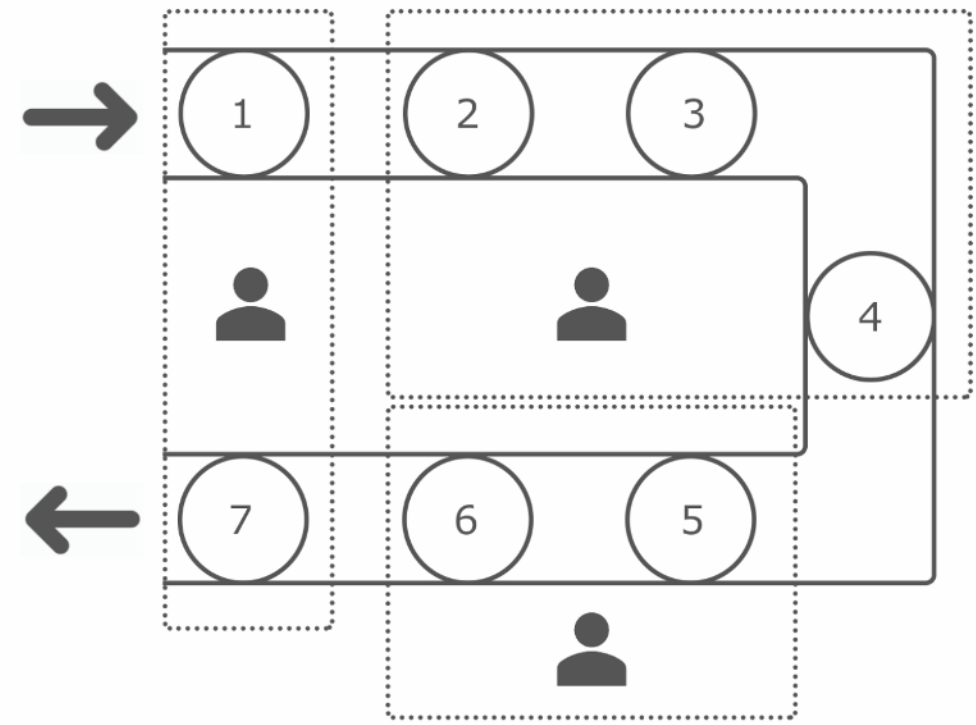
Each work cell will contain a unique set of equipment to manufacture this family of parts in an assembly line type of layout. The equipment is laid out in a U shape with equipment located close together so jobs do not have to move very far.

Advantages of a cellular layout include:

1. Reduced set up times for each piece of equipment because each machine is making products that are very similar, often set-ups are very fast or non-existent.
2. Speed is greatly enhanced because batches can now be small and goods that enter the system will continue until they are complete. Small batches means fast run times and short wait times.

3. Inventory investment is now reduced due to small batch sizes enabled because of the low set up times required.
4. Quality is enhanced because employees work only within that cell on a narrow range of products. Cross training of employees ensures good and thorough knowledge of the entire production process.
5. Employee morale is improved due to working as part of a team that has responsibility for the throughput and quality of the cell. The U-shaped design heightens collaboration among workers.
6. Less floor space is required due to machines being placed close together and less movement of product.

An example of a U-shaped layout can be found below:



Other Layouts

Office Layout: In 2020 office spaces are a great deal different than in generations past. Floor space per employee has dropped significantly. There is far less worry about the flow of paperwork than in the past. Often employees are grouped according to the tasks they perform and the work teams they participate in. Workspaces now tend to be more flexible with less paper and less furniture to hold files and documents. Many organizations put more emphasis on having comfortable spaces for collaboration. Layouts are much more open concept with lower partitions to improve visibility of the workspace.[1]

Retail Layout: The overall goal when laying out a retail location is to try and maximize the amount of sales per square foot in the facility. This is done by careful study of traffic patterns in the store in order to try and maximize the amount of product to which each customer is exposed. That is why you will often find the milk at the far end of the store causing customers the need to walk past all other departments to reach it.

Warehouse Layout: Effective warehouse layout aims to make effective use of the total volume of space contained in the building. The relationship between the receipt of incoming goods, the storage space and the picking, packing and shipping of outbound goods is carefully analyzed. An important consideration is the placement of inventory items in order to minimize distance goods and employees are need to travel. Many warehouses have special holding requirements such as freezers, cold storage and high security areas.

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1. Lashbrooke, B. (2019). This Is The Hottest Trend In Office Design Right Now, Retrieved on November 21, 2019, from https://www.forbes.com/sites/barnaby.../#5c26abb87787 ↵

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6.5: Some important “Times” to be familiar with-

Throughput time is the time between the beginning – the very first operation in the process until the product is actually completed at the end of the process. Remember that this includes not only the process time, but also any waiting time, inspection time, time spent on rework and movement.

Lead time is the amount of time between when the customers order is received and when the product is completed and ready to ship.

Cycle time is the rate at which the operation is actually producing each unit. If you stood at the end of the process and measured the time between completion of each unit, that is the true cycle time.

Takt time is a calculated value which determines the rate at which a firm needs to process their product in order to meet customer demand. It can be calculated by:

$$\frac{\text{available production time}}{\text{demand}}$$

Example 6.5.1

A firm operates 8 hours per day (480 minutes). Their daily demand is 120 units. They can calculate their takt time required to meet this demand:

(8 hours x 60 min) / 120 = 4 min.

The firm must product **one product every 4 minutes.** This is also known as the drum beat of the operation. They must produce one product at least every 4 minutes to meet customer demand. If demand increases it may be required to use continuous Improvement tools to change the takt time or possibly add additional equipment.

The above calculation shows that an assembly line must have a takt time of 4 minutes in order to produce 120 units per day. What if customer demand rose sharply? What would need to happen to increase the output?

Solution

The takt time would need to decrease (actually run faster). A takt time of 3.0 minutes would produce an output of 480 min / 3 min = 160 units. A takt time of 2.0 minutes would produce 240 units per day.

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6.6: Process Flowcharting

Any process improvement initiative will always begin with mapping out a visual representation of the current process. This is necessary so that all members of the team have a clear understanding of how current process is working. All of the steps and flows need to be identified and laid out in the proper sequence. It is important that the correct stakeholders are involved in this activity!

There are many different types of flowcharts, and many different software applications that can assist with this activity. Most practitioners tend to prefer using a large roll of paper on the wall where the group can collaborate rather than using a computer projected onto a screen. It is important to go out into the workplace and walk the process before beginning this task. This is a very standard activity that takes place in organizations around the globe. As an Operations Manager, there is a high likelihood that you will become involved in this at some point in your career. To map a process, a standard set of symbols are used. There are many different symbols, it is best not to get too caught up in all of them. The standard symbols include:

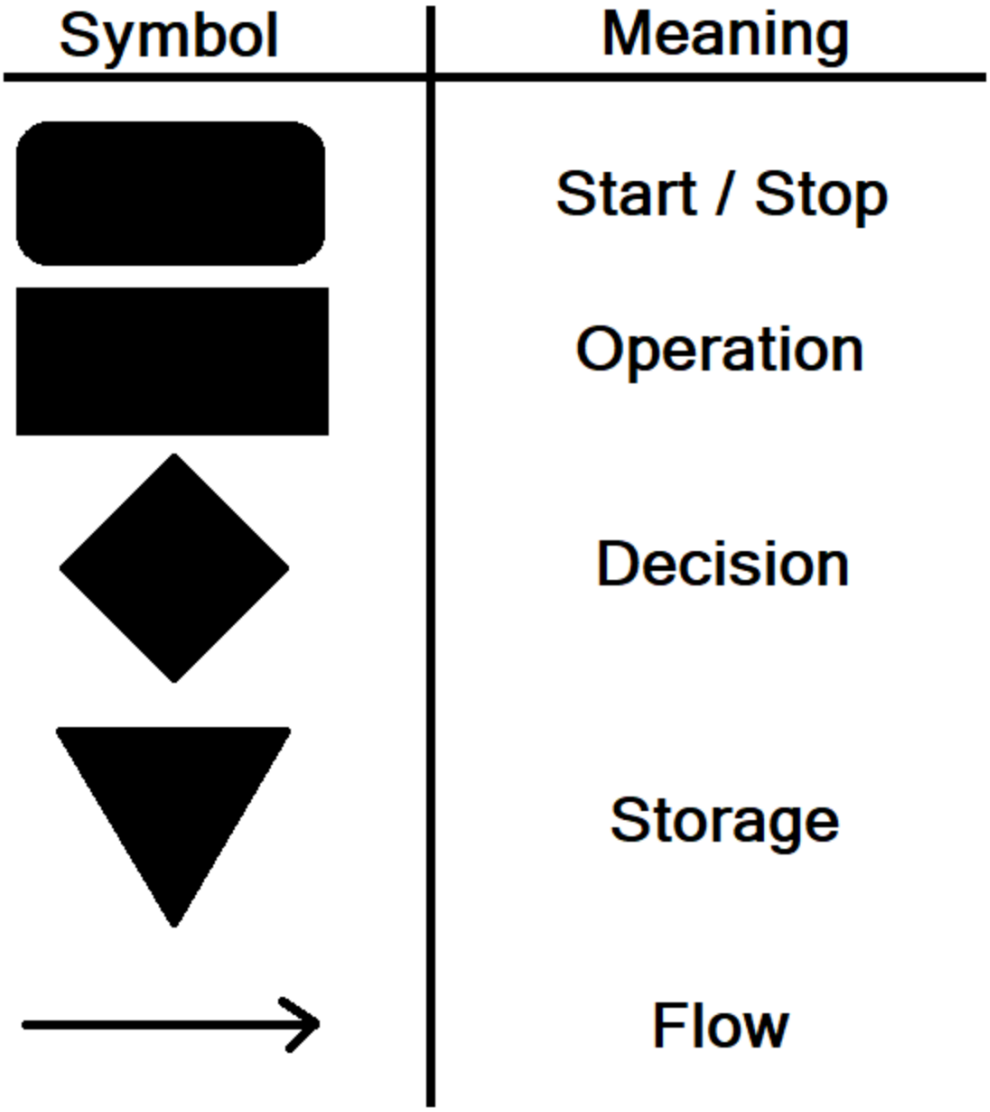

Figure 6.6.1: Flow chart symbols

For example:

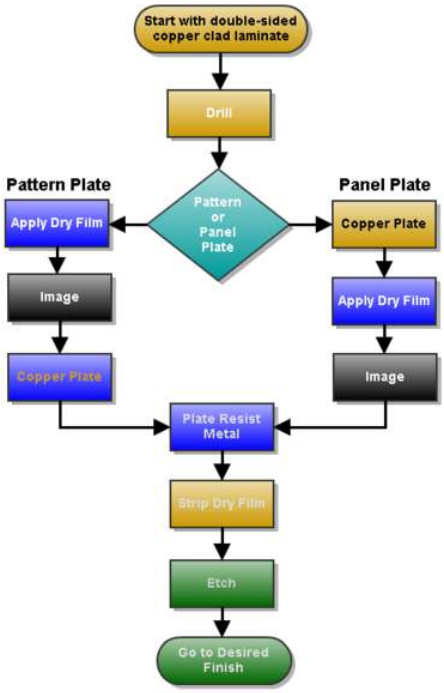

Figure 6.6.2: A typical flow chart

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CHAPTER OVERVIEW

7: Facility Location

There are many factors that can determine where an organization will locate its facilities. For any given situation, some factors become more important than others in how facility location affects an organization's performance. For example, when a company needs to open a new manufacturing facility, there are several factors that determine which location reduces the company's operating costs while providing a great level of responsiveness to the market.

7.1: Key Factors in Facility Location Decision-Making
7.2: Methods for Finding the Best Facility Location
7.3: Centre of Gravity Method

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7.1: Key Factors in Facility Location Decision-Making

- Proximity to sources of supply:
  - Firms that process bulk raw materials usually locate close to the source of supply to reduce transportation costs. Paper mills locate close to forests, canneries are built close to farming areas, and fish processing plants are located close to the harbors where the fishing vessels dock.
- Proximity to customers:
  - There are several reasons why an organization would locate close to end customers. Service firms need to be close to customers to be convenient, as is the case for grocery stores, gas stations, fast food restaurants, and hospitals. Transportation costs can also require proximity to customers, as in the case of concrete manufacturing. Perishable products often require that they be produced close to the final market, as is the case for bakeries and fresh flowers.
- Community factors:
  - Communities may offer a number of incentives to entice companies, including waiving or reducing taxes, and providing access roads, water and sewer connections, and utilities. Community attitudes can also play a role in an organization's location decision. Some communities may actively discourage companies that might bring more pollution, noise, and traffic to the area. Some communities may not want a prison to be located in their community. Other communities may welcome such firms because of the jobs, tax revenues, and economic diversity they promise.
- Labor factors:
  - Research shows that the majority of location decisions are largely based on labor factors, since labor is a critical variable for many firms. Labor factors include the prevailing wage rate in a community for similar jobs, the supply of qualified workers, and the average education level of the local population (percentage of high school graduates, etc.). Other labor factors can include the degree of union organizing and the general work ethic of a community, as well as other measures of absenteeism, and worker longevity in a job can play a strong role when a firm makes a location decision.
- Other factors:
  - Many other factors can play a role in the location decision, including quality of life (crime rates, good schools, climate, and recreation options), access to major transportation arteries, construction costs, proximity of the competition, and opportunities for future expansion.[1]

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7.2: Methods for Finding the Best Facility Location

Location Factor Rating

One method to assist in choosing the best location is the Location Factor Rating (also known as Weighted Scoring Model). The various factors important in this decision are decided upon and each is given a weight between zero and 1.0 to reflect each factor's importance. Every site is then evaluated in comparison with each other and given a score. Weighted scores are calculated by multiplying each score by its corresponding weight. When weighted scores are summed up, the highest weighted score reflects the location which is the most attractive based on all factors.

Example 7.2.1

Location Factor	Weight	Site #1	Site #2	Site #3
Proximity to Suppliers	0.3	80	85	80
Business Environment	0.25	65	90	55
Wage Rates	0.15	72	55	65
Community	0.1	65	60	40
Proximity to Customers	0.1	55	90	70
Labour Pool	0.05	40	45	65
Proximity to Airport	0.05	60	55	80

Solution

Weighted Score

Location Factor	Site #1	Site #2	Site #3
Proximity to Suppliers	24.0	25.5	24.0
Business Environment	16.3	22.5	13.8
Wage Rates	10.8	8.3	9.8
Community	6.5	6.0	4.0
Proximity to Customers	5.5	9.0	7.0
Labour Pool	2.0	2.3	3.3
Proximity to Airport	3.0	2.8	4.0
Total Score	**68.1**	**76.3**	**65.8**

In this example, site #2 shows the highest score when evaluated against site #1 and #3. So, we choose site #2.

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7.3: Centre of Gravity Method

In order to minimize transportation costs, the centre of gravity method may be used to locate a facility that serves several area (or other facilities) such as a warehouse or distribution centre. This method uses an (X-Y) coordinate system to cover the geographical map of the areas under study, and identifies the x and y coordinates for the location of the new facility based on the coordinates of the other facilities and the volume (quantity) of demand for each area (facility). For example, in the following figure, each blue star represents a market area that needs to be served, and the size of area also shows the demand quantity for that market. We are looking for the whereabouts (i.e., $\bar{x}$ and $\bar{y}$) of the location for our facility to be set up to serve all these markets while minimizing our total transportation costs.

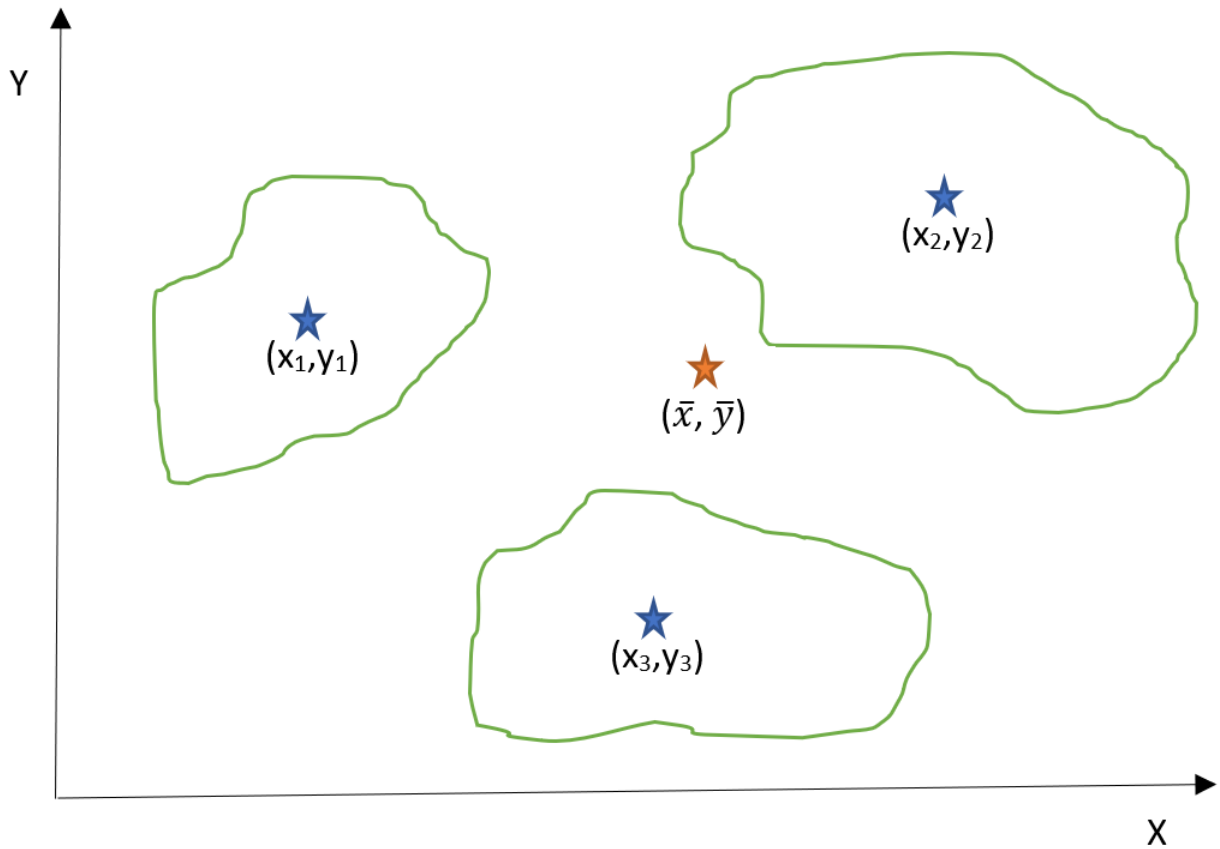

Figure 7.3.1: Three market areas on an X-Y coordinate axis.

In the following, we show the Centre of Gravity formulas. and use them in an example:

$$\bar{x} = \frac{\sum x_i Q_i}{\sum Q_i}$$

$$\bar{y} = \frac{\sum y_i Q_i}{\sum Q_i}$$

Figure 8.2:

$\bar{x}$ = the x coordinate for the new facility

$\bar{y}$ = the y coordinate for the new facility

x_i = x coordinate of destination (market) i

y_i = y coordinate of destination (market) i

Q_i = quantity to be transported to destination i

Example 7.3.1

Using the center of gravity method and the information on the location of the potential markets, determine where the new facility should be located to minimize the total transportation cost. Note that a selected point in the middle of each region is representing the regional market.

Market	Volume	X	Y
London	600	1	2
Toronto	400	3	4
Kingston	550	6	4
Barrie	800	2	6

Solution

$$\bar{x} = \frac{1(600) + 3(400) + 6(550) + 2(800)}{600 + 400 + 550 + 800} = 2.9$$

$$\bar{y} = \frac{2(600) + 4(400) + 4(550) + 6(800)}{600 + 400 + 550 + 800} = 4.2$$

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CHAPTER OVERVIEW

8: Supply Chain Management

Learning Objectives

- Explain the term supply chain, describe its flows, and the organizations that participate in a typical supply chain.
- Identify types of inventory in the supply chain and reasons for carrying inventory.
- Define the term logistics and give advantages and disadvantages to various forms of transportation.
- Describe the various forms of communication and technology in the supply chain.
- Calculate inventory turnover and days of supply as measures of supply chain performance.

8.1: Introduction to Suppy Chain Issues
8.2: Managing Main Flows in the Supply Chain
8.3: Foundational Elements of Supply Chain Management
8.4: Supply Chain Design
8.5: The Role of Inventory in the Supply Chain
8.6: Logistics
8.7: Distribution Management
8.8: Communication and Technology in the Supply Chain
8.9: Supply Chain Collaboration
8.10: Socially Responsible Supply Chain Management

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8.1: Introduction to Suppy Chain Issues

Supply Chain refers to the group of organizations that are linked together by their participation in order to fulfill a customer order from the sourcing of raw materials through the production of goods to distribution and sale. Each organization has a role to play in adding value for the final customer. The organizations that participate in a supply chain include suppliers, manufacturers, transporters (also known as carriers), distribution centres, wholesalers, retailers and end-consumers.

Every link in this chain of supply is very important. As they say, “a chain is only as strong as its weakest link.” This has implications for the supply chain management in a sense that it is not enough for the companies just to focus on their own internal operations. They need to regularly check with their supply chain members to make sure that everybody is performing at their best. One weak member in any supply chain will impact everybody else.

For example, if a retail store is not doing a good job at replenishing their inventory on time, the product will not be available to some end-consumers when needed, and as a result, lost sales happen and that supply chain will be affected financially. Let’s think about it for a second: fewer products had got ordered from the manufacturer, and thus, fewer raw materials were ordered (by the manufacturer) from higher tiered suppliers. This way, everybody in the supply chain sold less than what they could if the retailer had ordered the right quantity at the right time.

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8.2: Managing Main Flows in the Supply Chain

There are three types of main flows that happen in any supply chains: **flow of materials/goods**, **flow of money/cash**, and **flow of information**. There is a forward flow of materials/goods for the regular flow that happens all the way from higher tier suppliers (upstream) to the end-consumer (downstream). In addition, if there is any returns for any reason, there will be a reverse flow of materials/goods in the opposite direction to the forward flow.

Flow of money (cash flow) happens from downstream to upstream. For example, the retailer needs to pay the distributor for the goods they have received from them.

Flow of information happens both ways in the supply chain since organizations will need to share different type of information with each other so that the whole supply chain can make better decisions to improve overall performance.

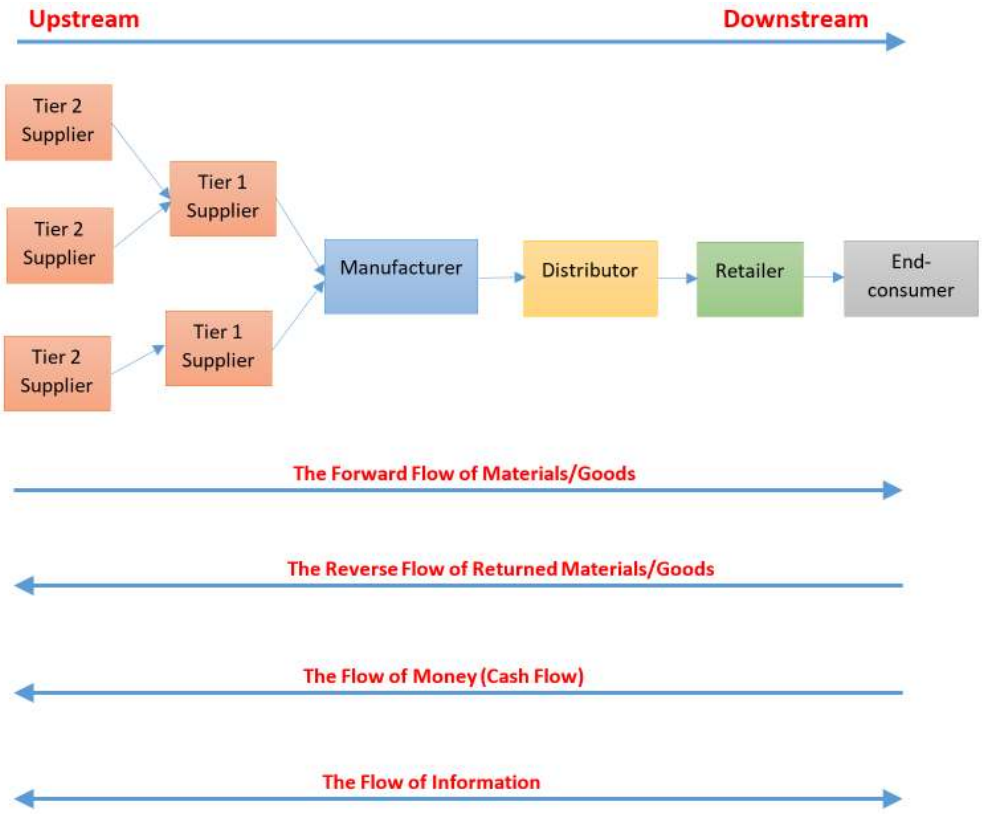

Figure 8.2.1: Upstream and downstream of a supply chain and its flows.

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8.3: Foundational Elements of Supply Chain Management

Each organization in a supply chain needs to manage four key elements. These include supply management, managing the internal operations, distribution management, and managing the integration of all of these so that all parts of the supply chain are working with each other in harmony. The following sections will cover some of the things that are done in relation to each one of these elements. Figure 4.3 depicts the foundational elements.

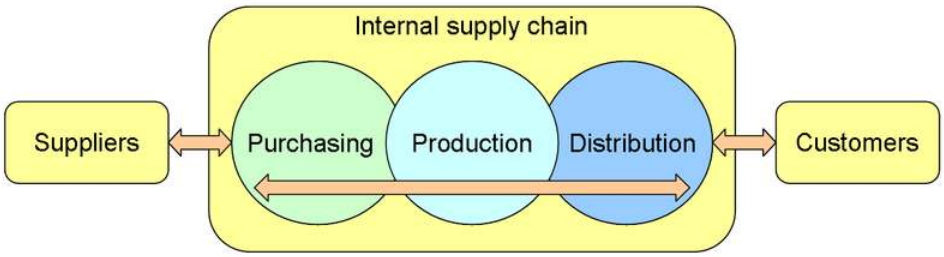

Figure 8.3.1: Example of a company's supply chain; Credit: Stern / Wikimedia / https://commons.wikimedia.org/wiki/F...chain_(en).png

Supply Management includes purchasing and managing the suppliers and the relationships with them. **Internal Operations** is consisted of managing whatever the company does to add value. For example, a manufacturer does "Production", along with managing inventory of raw materials and finished goods, human resources, etc.

Distribution Management deals with managing the customers and the relationships with them. In order to do this, the organization needs to have a deep understanding of its customers and their needs to be able to deliver the right product/service to the right customer at the right time. **Integration Management** uses several technologies such as ERP systems to make the collaboration among the different elements easier and more accurate.

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8.4: Supply Chain Design

Supply Chain Design is a strategic decision which determines who needs to take on what role or responsibility in the supply chain and where they should be located. Different companies choose different design or structure for their supply chains. For example, Walmart has always used traditional brick and mortar stores to serve its customers, while Amazon has been using an online platform to get customers' orders and then, ship them directly from their distribution/fulfillment centres.

When designing a supply chain, two main things to consider are Efficiency (cost reductions) and Responsiveness. The balance between these two could be different for different companies. That is, depending on the customers' preferences, the company decides to have a certain structure for their supply chain. For example, if the customers for a particular company are willing to wait for 5-7 days to get their ordered products online, the company can store its inventory in fewer locations and use the longer time of transportation to serve its customers. However, if the customers want to have their products right away, the company may need to open quite a few stores and keep enough inventory in each one to be able to respond faster to its customers' needs.

A company may decide to use other companies for parts of their supply chain or to have their own entities. This includes Vertical and/or Horizontal integration. Vertical integration is a term that is used when a firm owns more than one portion of its supply chain. For example, for a manufacturer company, they may have their own distributors or even retail stores to sell their products to the end-consumers (forward integration) or they may choose to own one or more of the suppliers that provide the company with certain materials or components (backwards integration).

Horizontal Integration is a situation where a business chooses to increase their holdings by acquiring or merging with another firm in the same market. An example of this was the 2015 merger of Kraft foods and Heinz, or Marriott International's purchase of Starwood hotels in 2016.

Example 8.4.1

A complex surrounding the Highland Park Plant included a power plant, machine shop, and foundry. Ford was starting to bring together the various stages in the manufacture of automobiles, a strategy called vertical integration. By the 1920s, Ford had purchased a rubber plantation in Brazil, coal mines in Kentucky, acres of timberland and iron-ore mines in Michigan and Minnesota, a fleet of ships, and a railroad. These efforts to vertically integrate helped Ford make sure his company would have raw materials and parts when they were needed, guaranteeing a continuously operating assembly line. These efforts also enabled the company to profit from more of the processes involved in producing the automobile.[1]

Example 8.4.1

Netflix is one of the most significant backward vertical integration examples in the entertainment industry. In the past, Netflix was established at the end of the supply chain because it was a platform to distribute films and TV shows created by other content creators. Although this was a profitable means of doing business, Netflix leaders realized that they could generate greater revenue by creating their own original content. This would offset their reliance on outside content creators, and fill what Netflix discovered was a desire among their subscribers for original content. Netflix leaders understood that they could leverage their existing distribution platform to promote original content to a captive audience. This strategy has become vital to Netflix's continuing success because as more and more film studios end their licensing agreements with the streaming giant, the company's original content will become the main attractor for new subscribers.[2]

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8.5: The Role of Inventory in the Supply Chain

Managing inventory is one of the most important activities in a supply chain. Materials/goods are needed to provide manufacturers with the exact items that they need, in the right order, the right quality, delivered to the right location, and at the right time. Without all of this happening, it will be impossible to produce high quality goods and meet commitments to our customers. In addition, when goods are ready for shipment, the outbound supply chain needs to be organized in such a way that customers receive their requested orders in a cost-efficient manner.

Types of Inventory in the Supply Chain:

- Finished goods
- Raw materials
- Purchased components and operating supplies
- Work-in-process

Reasons for holding inventories:

Many reasons exist for keeping stocks of inventory. Some of the most common include:

- Manufacturers often build up inventories throughout the year because of seasonal demand.
  - An example is a Chocolate manufacturer who does not have the capacity to produce all the product that is needed for Christmas. They may begin building inventory in late spring in order to have enough on hand for orders in November and December.
- At the same time, a manufacturer may carry large amounts of inventory if they have some uncertainty or risk in their supply base**.** If suppliers have some risk of shortages, work stoppages, poor quality or late deliveries then more stock may be carried.
- Firms may be tempted by extra discounts often provided by purchasing large order sizes. Perhaps they may want to minimize transportation costs. There may also be some worry about future price increases that can cause organizations to build up their inventories.
- Retailers carry inventory to ensure that they do not run out of what they anticipate their customers may want. Distributors and retailers may try and balance the cost of keeping large inventories on hand with providing excellent customer service with few or no disappointed customers. However, it is often a challenge to anticipate exact customer behaviour.
- It is a challenge to synchronize incoming flow of materials and goods in order to meet production schedules and ship to customers as promised. As a result, inventory may be stored at many locations along the supply chain. This causes extra cost and inefficiencies for each organization.

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8.6: Logistics

Logistics refers to the activities of coordinating and moving resources, particularly inputs into the transformation process, and finished goods out to customers. Originally, the term logistics was from the military and referred to moving troops, equipment and supplies. Managing logistics involves making decisions such as the following:

- Choosing to operate and manage the firm's own transportation, or whether to outsource this activity
- Selecting suppliers that have the capability to ship goods safely and securely within the required time frame
- Choosing the correct mode of transportation and the most effective route
- Negotiating the shipping rate

Modes of Transportation

There are several modes of transportation available to companies. We discuss them in the following:

Trucking

The majority of goods are shipped by truck completely or at some point during the shipping. Trucking is the most flexible of all modes of transportation. Trucking is categorized by "truck-load" (TL) when the entire truck is hired and delivered directly, or "less-than-truckload" (LTL) which generally includes using several orders to increase the utilization of the truck. A serious issue facing Canada at this time is the expected shortage of qualified drivers. Demand for drivers continues to increase every year, and the average age of drivers is increasing. The trucking industry will face challenges to make driving more attractive to entice new workers into trucking jobs.[1]

Railroads

Rail can be a very cost effective means of transporting goods that need to travel long distances. Goods in containers, or products that are bulky and heavy are ideal for train transport. Canadian rail ships products including cars, fertilizer, food and beverages, forest products, grain, metals and minerals and petroleum products. Often, large manufacturers locate themselves near rail lines to make for easy shipment of raw material into, and finished goods out of their facilities. Compared to trucking, shipping by rail is very energy efficient, and removes many trucks from congested highways. Canada has a very old and well-established rail system.[2]

Airfreight

For goods that are expensive, small and light, air shipping may be a good choice. Air carriers charge by a combination of the weight and size of the shipment. This mode of transport is generally used when speed is more important than cost. Shipping by air is very reliable. Firms may want to consider the environmental impact of regular use of air shipping.

Waterway

This is a very common way of shipping goods. The goods that travel by water include chemicals, stone, cement, sugar, coal and other heavy commodities. Millions of containers travel by ship each year. Do you know what goods travel by ship? Read here.

The Great Lakes St. Lawrence Seaway System is a 3,700 kilometer marine highway that runs between Canada and the United States. Opening in 1959 the seaway is a major trade artery that serves many industries to ship iron ore, coal, limestone, steel, grain and cement. The cost for shipping by waterways is inexpensive. Most low-cost products are shipped by waterways.3

Pipelines

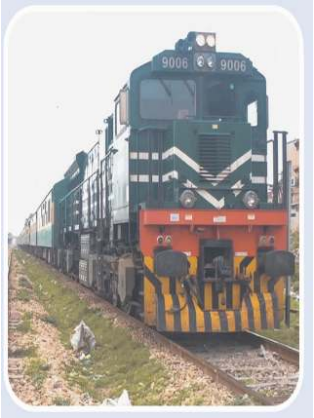
Crude oil, natural gas and other petroleum products are shipped by pipelines. Once the pipelines are built, the cost per kilometre for shipping is very inexpensive. There is a lot of opposition and concern over new pipelines because of worry over spills and leaks that may contaminate land and waterways.[4]

Multimodal/Intermodal shipping

This refers to the use of a combination of different types of transportation to move goods from origin to destination. A common example is a combination of truck/ship/train. The goal is to ship the goods as efficiently as possible. The goods are shipped under a single contract with a carrier, and can be easily tracked. It also uses several modes of transportation but also uses a container so that

freight does not have to be handled each time it changes modes. Each mode will have a carrier responsible for the shipment. The use of containers increases the security, reduces loss and damage and increases the speed of shipment.

Diagram summarizing various modes of transportation.

		
TRUCKING • Flexible (truck load vs less than a truck load • Drivers in demand • Creates highway congestion	RAILROADS • Ideal for bulkier products or containers • Cost effective over distances • Energy efficient	AIR FREIGHT • Ideal for small and light products • Prioritizes speed over cost • Reliable • Air pollutant
WATERWAY • Ideal for low cost, heavy products • Very common • Inexpensive	PIPELINE • Used for crude oil, gas, petroleum • Once built very cost effective	INTERMODAL • Uses a combination of modes through a carrier

	• Land and water pollutant	• Products secured in containers • Contractual with a single carrier

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8.7: Distribution Management

Distribution management refers to the process of overseeing the movement of goods from supplier or manufacturer to point of sale. Distribution management is an important part of the business cycle for distributors and wholesalers. The profit margins of businesses depend on how quickly they can turn over their goods. The more they sell, the more they earn, which means a better future for the business. Having a successful distribution management system is also important for businesses to remain competitive and to keep customers satisfied.

Distribution involves diverse functions such as customer service, shipping, warehousing, inventory control, private trucking-fleet operations, packaging, receiving, materials handling, along with plant, warehouse, store location planning, and the integration of information.

The goal is to achieve ultimate efficiency in delivering raw materials and parts, both partially and completely finished products to the right place and time in the proper condition.[1]

The combination of distribution and transportation is **logistics**. The most important factor in any logistics is quickly delivering product in perfect condition. Read here how Amazon has used its supply chain management to fuel its rise to the top.

Crossdocking

A broad definition of **crossdocking** is the transfer of goods and materials from an inbound carrier to an outbound carrier without the products actually entering the warehouse or being put away into storage. Thus, the products "cross the docks" from the receiving dock area to the shipping dock area. It can provide significant inventory savings, and the cost of holding inventory and the costs of handling the inventory are reduced. Crossdocking helps to provide excellent customer service by speeding up customer deliveries.[2]

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8.8: Communication and Technology in the Supply Chain

Electronic Data Interchange (EDI)

Electronic Data Interchange (EDI) is the computer-to-computer exchange of business documents, such as purchase orders and invoices, in a standard electronic format between business partners, such as retailers and their suppliers, banks and their corporate clients, or car-makers and their parts suppliers.

EDI enables the companies to transfer the documents without having any people involved. The documents are automatically transferred from one computer (account) to another. As a result, there are many advantages to using EDI. The primary benefit is the speed and accuracy of the information transmitted. Information is made available in real time and errors that may have previously been caused during the data entry process are eliminated.

Common information exchanged using EDI include:

- Purchase orders
- Invoices
- Advance shipment notices (ASN)
- Customs documents
- Inventory information
- Shipping status
- Payment documents
- Bill of lading
- Sales/price catalogues
- Shipment status messages

Barcodes

Barcodes have been used extensively since the 1970s, and consist of data that is displayed in a machine-readable form that can be scanned by barcode readers. The information contained on the barcode is typically pricing information, product number and description and any other pertinent information. Barcodes have become the norm in retail operations allowing for pricing accuracy and easy price changes. This data provides point-of-sale information to allow retailers to track items being sold, update inventory, identify fast and slow moving products and assist in forecasting.

QR

Quick Response (known as QR) is using bar codes and EDI to make sales data available to vendors so that vendors can quickly replenish goods in the correct quantity. This is thought of as JIT in the retail industry. The goal is to reduce out-of stock incidents, as well as using smaller more frequent deliveries to reduce inventory and operating expenses.

Radio Frequency Identification Device (RFID)

This technology uses radio waves to communicate information contained on a tag attached to an object. The information contained on a tag may include things such as the products origin, date of production, shipment information, pricing info, and any other pertinent info. In order to transfer this info, both a tag and a reader are needed. There are two types of tags, active and passive. An active tag contains a power source such as a battery and can operate a great distance from the reader. Passive tags use energy from the reader. Unlike barcodes, the RFID tag and reader do not require line of site in order to transmit the information.

RFID applications include the following plus many more:

- Retail use to protect from theft
- Toll road payments
- Identification (i.e. tracking of animals and people)
- Passports
- Shipping tracking – to identify location and contents of orders
- Asset tracking (e.g. laptops, expensive tools, medical devices in hospitals)

- Race timing for marathons
- Tracking luggage during travel

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8.9: Supply Chain Collaboration

Vendor Managed Inventory (VMI)

Vendor Managed Inventory (VMI) is an advanced supply chain relationship whereby a vendor (often a manufacturer) has access to their customer's inventory information and the vendor takes the responsibility for maintaining an agreed-upon level of product at the customers location. This arrangement can be used with manufacturers, distributors and retailers.

VMI has numerous benefits for both the supplier (vendor) and the customer. The vendor has strong motivation to ensure that shelves are fully stocked, any slow-moving stock is discontinued and that employees have full understanding of the product offerings. The customer benefits from these VMI relationships because less work is involved on the buyers' end. Due to EDI, there are few errors and goods flow quickly. Point-of-sale data updates the inventory and determines what items are needed. Salespeople from the vendor often provide assistance by training sales staff and assisting customers when possible.

Collaborative Planning, Forecasting and Replenishment (CPFR)

Collaborative Planning, Forecasting and Replenishment (CPFR) is an arrangement where two trading partners in a supply chain collaborate to agree on forecasts and orders between the manufacturer and distributor/retailer. The distributor/retailer will have collected POS data and added any additional information, such as promotion plans, inventory status or forecasts. That information gets shared with manufacturers who will then compare it with their own forecasts and capacity. Both teams can collaborate to solve any discrepancies, eliminate gaps and agree on a final set of numbers. Collaborating in this way will enable both firms to reduce inventory as well as reducing problems such as shortages and capacity problems.

Inventory Turnover

Key Performance Indicators are measurements used to evaluate supply chain performance. One of the ways to evaluate the supply chain performance is to calculate **inventory turnover** (inventory turns = *cost of goods sold divided by average aggregate inventory value).*:

$$\text{Inventory Turnover} = \frac{\text{Cost of goods sold}}{\text{Average Aggregate Inventory Value}} \tag{8.9.1}$$

"Average aggregate inventory value" is a term used to describe all of the inventory held in stock, which includes raw materials, work in process and finished goods, all valued at cost.

Inventory turnover is an indicator of the policies and practices of an organization. It represents their ability to purchase materials, produce and sell their products in a timely manner. A higher value for the inventory turnover means that the organization has been capable of replenishing and selling its inventory more number of times in any particular amount of time, and as a result, have a better cash flow.

It is important to keep in mind that high or low value of inventory turnover for each company is relative to its own industry. For example, dairy (milk) manufacturing has an annual inventory turnover of around 23, while this number is 14.7 for the grocery supermarkets, and 4.8 for the automotive industry.[1] Industries with higher volume, but lower margin, usually have the highest inventory turnovers.

Example 8.9.1

NED's Food Supply is a supplier to restaurants and institutions for frozen foods, meats, fish, canned and fresh fruits and vegetables. Here is an analysis from the past two years regarding their inventory management. In which year was their supply chain performance better?

Cost/Value	Last year	Two years ago
Cost of goods sold	17,550,000	16,255,000
Average aggregate inventory value	$1,650,000	$1,763,350

Solution

Inventory turns for last year = 17,550,000 / 1,650,000 = 10.64 turns

Inventory turns for two years ago = 16,255,000 / 1,763,350 = 9.22 turns

Last year, their inventory turnover was faster. If customer service was equivalent in both years, then their performance was better last year than it was two years ago. This may have resulted in customers receiving fresher foods as well.

Days of Supply

Another related performance measure is **days of supply**:

$$\text{Days of Supply} = \frac{\text{Average Aggregate Inventory Value}}{\text{Annual Cost of Goods Sold}} \times 365 \text{ days} \tag{8.9.2}$$

Days of supply formula (average aggregate inventory value divided by annual cost of goods sold, the sum of which is multiplied by 365 [days]).

Example 8.9.1

J's Custom Automotive Finishing has calculated that his annual cost of goods sold at 45,000,000. His average inventory value in 2019 is:

Production components	2,350,000
Production supplies	450,000
Finished goods	225,600
Total aggregate inventory value:	**3,025,600**

Solution

Days of supply = (3,025,600 / 45,000,000) x 365 = 24.54

This measure can be thought of as how much inventory is sitting in the building at any one time. In terms of measuring the efficiency of the inventory, a lower number is better. It would imply that goods are purchased more frequently and spend less time in the facility before being converted into sales.

There are other ways to measure supply chain performance as well. In a warehouse or distribution setting, **fill rate** is an important measure. It is the percentage of customer orders that are filled from on-hand stock. In a manufacturing setting, a measure such as the **percentage of orders delivered on time** is an important indicator of customer service level.

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8.10: Socially Responsible Supply Chain Management

Main areas of social responsibility in supply chains are:[1]

- Organizational practices
- Ethical practices
- Environmental practices
- Practices of human rights and working conditions
- Practices of occupational health and safety
- Practices to establish relationship with society

The following table[2] summarizes activities and practices considered good examples for the CSR areas listed above.

Relevant CSR Areas	Sample Practices
Organizational Practices	• Determining CSR goals for purchasing function • Determining and defining roles and responsibilities of human resources related to CSR in logistics • Providing relevant training in CSR to the suppliers • Sharing of CSR activities and practices with all relevant stakeholders • Implementing a mechanism to receive feedback from stakeholders regarding CSR practices
Ethical Practices	• Not accepting gifts, free services, etc. from suppliers (especially during supplier selection process) • Not creating illegitimate pressures on suppliers • Not sharing price and service information about suppliers with other irrelevant stakeholders • Not favoring any particular supplier just because of managers' preferences and assuring a fair selection process • Assuring all departments meet ethical standards in independent purchasing process • Not creating illegitimate advantage in competition by using contract items • Not giving out wrong information on purpose • Not using specific items pointing out specific suppliers in contracts
Environmental Practices	• Purchasing and using recycled materials for packaging • Supporting and encouraging suppliers on reducing waste (especially hazardous waste) • Putting special emphasis on producing recyclable and reversible materials in production and design • Meeting standards for protecting environment in the processes of lifecycle management, production, packaging and storing • Supporting suppliers to implement processes that are appropriate for sustainable environmental protection
Practices of human rights and working conditions	• Not keeping some suppliers out of cycle, just because they have managers from different backgrounds • Having procedures and also having mechanisms to monitor providing equal opportunity for each employee working in all supplier companies • Having appropriate procedures in place to assure that all employees can benefit from all their legal rights, are working in accordance with rules, regulations and national/ international standards • Assuring that physical and psychological working conditions comply with all rules and regulations in place
Practices of occupational health and safety	• Having appropriate procedures in place to assure that working conditions do not jeopardize human health and safety • Assuring that all safety, security and protection measures are in place for all activities • Having procedures in place to assure that sensitive and delicate products are stored under appropriate conditions

Relevant CSR Areas	Sample Practices
Practices to establish relationship with society	• Developing and carrying out programs for training and development of local suppliers • Actively participating into and organizing non-for-profit social activities, such as volunteer work, charities, public auctions, etc. • Supporting sport activities and public education

Among those aforementioned activities, ensuring that all activities and functions comply with national / international rules, regulations and standards and working with suppliers that fulfill same requirements constitute the most important factors for CSR in supply chains. This issue is also important to stay competitive in market and to have a sustainable growth in terms of strategic perspective.

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CHAPTER OVERVIEW

9: Inventory Management

In this chapter, we are going to talk about inventory management models that deal with certain or known demand. The basic questions that any inventory management model tries to address are 1) how many units to order, and 2) when to place the order for those units. The objective of any inventory control or inventory management is to achieve satisfactory levels of customer service while keeping inventory costs reasonably low. So, there's always a trade-off between how much inventory you keep versus the level of customer service that you provide.

9.1: Types of Inventory

9.2: Inventory Management Models

9.3: Relevant Costs

9.4: Inventory Models for Certain Demand - Economic Order Quantity (EOQ)

9.5: Inventory Models for Certain Demand- Economic Production Quantity (EPQ)

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9.1: Types of Inventory

There are several types of inventory in any organization. Here are some that are more common:

- Raw materials or purchased parts are some of the very common types.
- Work in process (or progress) or WIP, which are the semi-finished or not completely finished items that you can find in the middle of assembly lines and manufacturing facilities.
- Finished goods or merchandise that we're all familiar with. We can find these in all the stores that we go to buy what we need.
- Spare parts or tools and supplies are also another type of inventory that companies may need basically

Reasons for Keeping Inventory

There are different reasons for keeping or holding inventory. Here are some examples:

- To hold inventory simply because that inventory is still in transit. In that case, it has not got to their facility yet and because they have paid for those items, they are counted as their inventory and this is something that we also call in transit inventory holding.
- To protect against the stock outs. This is a very common or probably the most common reason for keeping inventory. That is, when the customers come to ask us for a unit of product to purchase, we want to make sure that we have enough in stock.
- To take advantage of some quantity discounts that might be available to us by our suppliers. What happens is that our suppliers may tell us that if we purchase more, they will be able to give us some discounts. Note that we did not necessarily need the extra units at this time. As a result, we will need to keep them in stock and that will be our extra inventory to hold. We're going to talk about the discount model in this video as well and over there, you'll see what kinds of trade-offs are there and in which scenario it is better to take advantage of some discount versus not.
- To smooth out the production requirements. This simply means that from time to time, if the demand goes up and down, when the demand is down, you may want to produce a little bit more and keep it in inventory, so that later on, when the demand goes back up, you don't have to necessarily ramp up your production too much. But instead, you can use the inventory that you have piled up. This helps you keep a more steady production level at all times, which is usually a less costly way of doing the production.
- To cover for any disruption in the operations. This means if anything goes wrong in a certain part of a production process, you will have enough inventory around to cover you for that part of the operation. This way, you will most likely not have to shut down the whole production line, or you can at least delay the shutdown as much as possible, until the problem gets resolved.

Please note that in any of these scenarios, we will need to pay a close attention to the holding costs of the inventory versus the other costs. For example, if the inventory holding cost is very high, we may prefer to have a potential stockout sometimes as opposed to keeping a lot more inventory in stock. In another example, we may not use the discount option from our supplier if we know that the total savings (as a result of the discount) is not worth the additional inventory holding costs. We will discuss more about the inventory holding costs later in this chapter.

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9.2: Inventory Management Models

Generally speaking in inventory management, we look at the demand as an either known or more steady demand versus uncertain demand. We also have other factors to impact the type of model used. Lead time is one of these factors. *Lead time* is defined as the time from when you place an order to a supplier until you receive that order. Another factor is the review time. Review time is referring to how you review your inventory levels. For example, one method is called *continuous review*, which means that your information system will automatically check your inventory level at all times and when the inventory level hits a certain point, which we call the *reorder point*, the system will notify us that we need to place an order or even in more automated systems the system may automatically place the order and that way, we do not have to do anything. The order will automatically be placed to the supplier that we have an agreement with already.

Another type of review method that we have is called *periodic review* or *fixed order interval*. In this method, we check the inventory level at the end of certain fixed order intervals and if our inventory is less than a certain maximum level (which we can optimally determine beforehand), we will calculate how much difference is there, and we will place an order for that amount.

There are also other factors to be considered which we are not going to go into that much detail of those things here. For example, if there is any perishability or obsolescence, especially for items like food that can get perished. If so, that can make the inventory models a bit more complicated. In that case, we should consider the life span of the product that is perishable to make sure that we are not bringing in too much, or otherwise, it will be perished or obsolete, and the whole thing would be a total waste of our money.

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9.3: Relevant Costs

The costs are usually defined for each item or stock keeping unit (SKU) separately. As a result, the optimal order quantities and the time of order is determined for each item specifically. The relevant costs that we have in any inventory management are as follows:

Total Purchasing or Acquisition Cost:

This refers to the total purchasing cost of an item in a year (or in a month or a quarter of the year, etc., depending on what our unit of measure is for the time). In some models, this particular cost may not change. This is because the total demand in the year is the same (in those models) and if the price is not changing (that is, there's no quantity discount available from the supplier), the total acquisition cost or purchasing cost will be fixed. As a result, in those scenarios, we ignore this cost from our mathematical model, since we are doing our calculations to find the optimal order quantities and because this is a fixed cost and it does not change based on how much we order every single time, the total acquisition cost or purchase cost in the year will stay fixed.

Total Ordering Costs:

Ordering cost usually includes the clerical and retrieval expenses. Sometimes, we include the delivery and inspection a part of this cost too. If you have your own manufacturing (instead of buying from an outside supplier), this same cost will be called *setup cost* which we have it in the model that we call Economic Production Quantity (EPQ).

Total Carrying or Holding Costs:

This refers to the total cost of holding the items as if they were kept in stock for a whole year. Since each item will usually not stay in stock for the whole year, if we are to calculate the total annual holding cost, we will need to find an average number of items that we can find in our stock every time that we check our inventory. For example, if we checked our inventory level for a certain item 20 times during a year, we would most likely get a different number every time. If we take the average of those 20 numbers, that will give us a good estimate of how many units are sitting in our warehouse at all times. Please note that the items come in and go out of our facility as we buy and sell (or use) them. So, the items that we see on the stock each time are not necessarily the same ones sitting there for so long.

The unit holding cost is defined as cost of holding one unit of product for one unit of time. The unit of time is usually one year. But it can be based on a quarter, month, day or any other time unit. The key is to be consistent with the unit of measurement for time wherever in our calculations.

In operations management, we usually calculate the holding cost for each item as a percentage of the item's value. For example, if the value of the item that we are keeping in stock is $1000 and our inventory holding cost is 20%, this means that if we keep that item for one whole year, it will cost us 20% x 1000 = $200 per unit. If the same item sits in our inventory for only a quarter of the year, it will cost of (1/4) x 200 = $50 per unit. If we had 10 of this item and they were kept for one whole year, the total annual inventory holding cost would be 10 x 200 = $2000.

> *Insight:*
>
> *"If the price or the value of the item is higher, the holding cost will be higher. That is one of the main reasons that when companies are dealing with more expensive items, they tend to keep as few units as possible for those items. Sometimes, they keep only one unit just for showing at their store, and they get the customers' orders to deliver the item to them later, or to bring it to the store for customers' pickup later. They could not afford keeping several of those very expensive items in the store, because otherwise, the cost of holding them would be very high."*

The holding cost percentage represents all the costs associated with the facility in which the item is kept as well as any material handling costs within the facility. Basically, you will need to talk to the accountants in our company, if you are in charge of inventory, to get a better sense of the costs and a better idea of this percentage. In this chapter, we will have this percentage given to us in any examples that we have.

Some of the costs included in the holding cost percentage are as follows:

Cost of capital

This means that when your money is tied to the inventory that you are keeping, you cannot invest that money anywhere else. So, you are losing some sort of an opportunity out there. As a result, the estimation of an interest that you could have gained can give us a percentage which is used as a part of the holding cost percentage.

Insurances

Since we always need to have insurance for our warehouses, the cost of insurance can be calculated as a percentage for each item. This cost will in turn be used as another part of holding cost percentage.

Storage costs

As share of the actual cost of owning or leasing the warehouse or the facility in which we hold the inventory and the costs of running the place (e.g., material handling, utilities, etc.) are calculated per item and added to the holding cost percentage.

Breakage or spoilage

If there is any breakage, theft or spoilage that happens to our stock from time to time, we will need to add that as an additional part of the holding cost.

Shortage Costs

There could be some penalty or shortage costs if there were uncertainties in the demand. If the demand were higher than what you have available in your inventory, you would have a shortage. This cost is usually a tricky one, since it does not look like a cost for which you lose money out of your pocket right away. But in fact, you are not gaining the money that you could make if you had enough units of the item in demand available. You can also lose the sale to certain customers completely, as they may find substitute products from other companies. In addition, there is a chance for a loss of goodwill in our customers, specially if the shortage happens over and over again. In all these cases, the inventory management tries to monetize the amount of loss to plan more properly for an optimal level of product availability.

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9.4: Inventory Models for Certain Demand - Economic Order Quantity (EOQ)

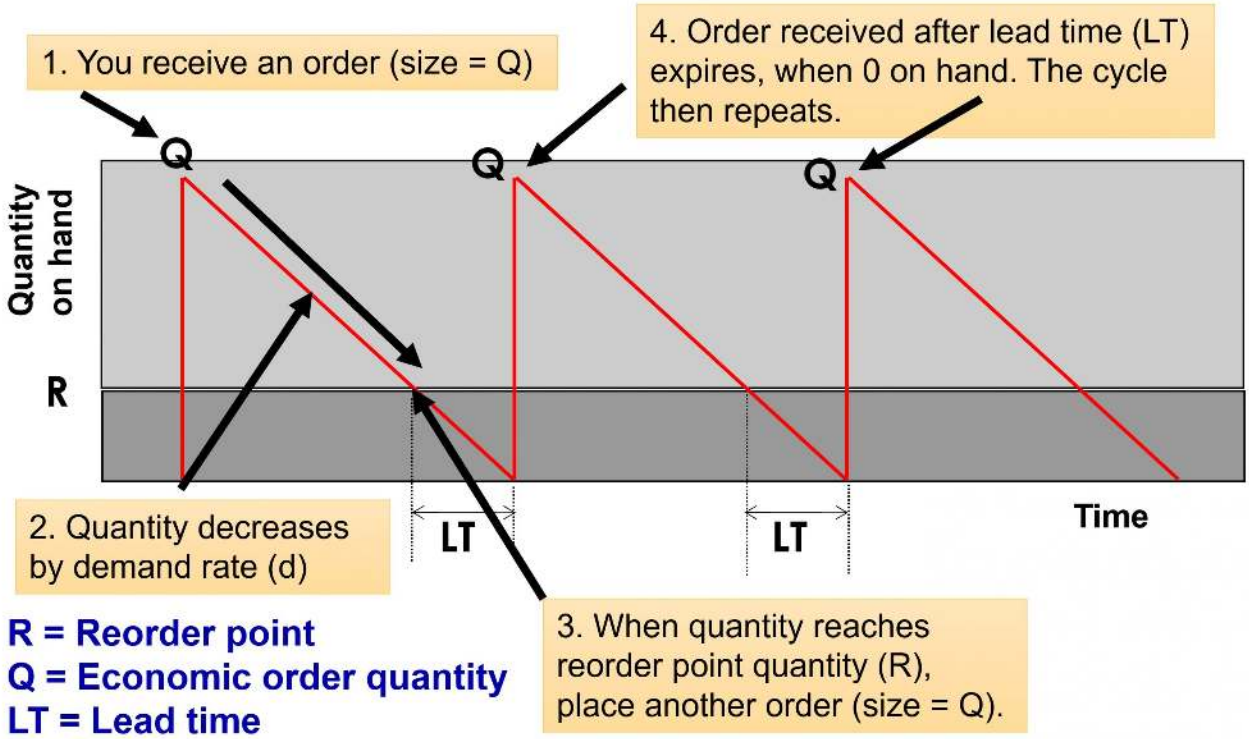
The very first model that we want to talk about is the simplest model out there, and is called Economic Order Quantity or EOQ. This model is very famous and the assumptions or conditions under which it works are as follows:

- We are ordering the product or item from an outside supplier. That is, we do not have our own production of the item.
- The demand is fixed or steady per unit of time (e.g., per year). Because the demand is fixed or known, there's no reason to have a shortage. Basically, it means that you know exactly how much money you are going to make if you bring in enough number of units to satisfy that demand.
- The lead time is constant. That is, there is no uncertainty because of the lead time either. So, if your supplier tells you that they are going to deliver in five days, you can certainly assume that five days is exactly five days and it is not going to be seven or it is not going to be three or four either.
- We order a fixed amount or the same amount every time that we place an order to our supplier.
- Our ordering cost is a fixed cost per order. Sometimes, when we order a greater number of units, our ordering cost per unit may change. But here, we are assuming that the ordering cost per order is simply the cost of administration in terms of placing the order and putting together the paperwork, etc. So, this simply means that if we order a larger or smaller lot size, it will not affect our ordering cost for that one order. But, it will change the number of orders that we place in a year. For example, if we order a larger lot size every time (note that all orders throughout the year are equal in size, based on the previous assumption), we will end up placing fewer number of orders in a whole year, and that will result in our total ordering cost in a year going down.

Inventory Control Cycles or Order Cycles

Usually, every order is associated with what we call an order cycle. We place an order and the order comes in, and then, we use the order that has come in to satisfy the demand, and then later on, when our inventory level gets down to a certain level, we place another order and after that, the same things get repeated again and again. That's why every one of these is called a cycle which gets repeated.

The picture below shows how the inventory level can change during the time:



The vertical axis is showing us the inventory level on hand, and the horizontal the time. The red line is showing the inventory level. At point #1, we receive an order. That is why our inventory level jumps up all the way from zero to Q units (Note that in the EOQ

model, we order Q units every time we place an order to our supplier). As time passes (which is from left to right), the inventory level goes down due to the customer demand that we are satisfying from the inventory that we have on hand. Then, our inventory level gets to a certain point that we call R or reorder point. That is exactly the time that we need to place our next order.

Because we do not want to have shortages, we consider a period of time which is equal to lead time and we go back in time for that amount (i.e., the duration of lead time) from when we expect our inventory level to hit zero, and we place the order right then. This way, we will have just enough inventory from when we place the order, which is at the reorder point, until the end of lead time, which is when our inventory is expected to hit zero, and exactly when we expect to receive our order.

The only reason that we can do this with such confidence is that as mentioned before, the demand rate is fixed. As a result, we know exactly how the demand is changing and how much ahead of the time we need to place this order so that we received it just as we are about to run out. The time from when the order comes in until when the next order is received is called *cycle time*.

The EOQ Model Calculations

The objective of the EOQ model is to find the optimal order quantity (the size of the order that we place each time) which can minimize our total costs. As mentioned under the section for relevant costs earlier in this chapter, some costs may not be included in the calculations for different reasons. For example, the total acquisition (purchasing) cost is not included in the EOQ model without discounts, because that total amount stays the same no matter what order size we use throughout the year. We discussed this earlier. In addition, some costs like the shortage cost are not included because the assumptions or conditions behind the EOQ model will automatically result in no shortage. As a result, there will not be any shortage to consider.

The only costs that are applicable to the EOQ model are the total ordering cost and the total inventory holding (carrying) cost. In our calculations in the following, we will calculate these costs for one whole year, and our goal is to minimize the sum of these costs in a year by finding the optimal order quantity.

Here are the notations and some basic calculations:

S = order cost ($/order)

H = carrying cost ($/item/year)

D = demand (units/year)

Q = order quantity

N = number of orders per year

I_{avg} = average inventory

Total cost	=	ordering cost	+	carrying cost
TC	=	$S \times N$	+	$H \times I_{avg}$
TC(Q)	=	$S \times D / Q$	+	$H \times Q / 2$

Note that S is the fixed order cost per order. N which is the number of orders per year can easily be calculated. We know that in total, we need a demand of D units to satisfy in a year and we also know that we are bringing in Q units each time. For example, if the demand is 1000 units per year and if you order quantity happened to be 100 units, we will need to place our order 10 times throughout the year, which is 1000/10.

About the average inventory, as mentioned in the section on relevant costs earlier in this chapter, we use the average inventory level to represent the inventory that we can see in our facility at all times during the year. That is why we multiply that by H which is the cost of holding one unit of inventory for one whole year. Please note that as mentioned before, the time measurement unit does not have to be in years. But if we needed to use a different time unit, we will need the other parts of the calculations (in this case, the demand) to be consistent with it to make sure they are all defined based on the same time unit of measurement.

Since we want to minimize the total cost by finding the optimal order quantity, we will need to use the function that we have for it (called TC(Q) here) and find the value of the Q that makes the derivate of this function equal to zero. Assuming that we have done all that, the final result is as follows:

$$EOQ = Q^* = \sqrt{\frac{2DS}{H}}$$

The * on top of Q shows that it is a special value of the Q, in this case, the optimal value. Let's have a look at some examples.

Example 9.4.1

Assume that Apple Canada has an annual demand of 250,000 for one of its tablets. A component has annual holding cost of $12 per unit, and ordering cost of $150. Calculate EOQ, total cost of ordering and inventory holding, number of orders per year and the order cycle time for this item. Assume 250 working days in a year.

Solution

$H = \$12\ per\ unit$

$S = \$150$

$D = 250{,}000\ units$

$$EOQ = Q^* = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2 \times 250{,}000 \times 150}{12}} = 2500$$

$$TC(Q^*) = S \times \frac{D}{Q^*} + H \times \frac{Q^*}{2} = 150 \times \frac{250{,}000}{2500} + 12 \times \frac{2500}{2} = 15000 + 15000 = \$30{,}000$$

$$Optimal\ number\ of\ orders\ per\ year = \frac{D}{Q^*} = \frac{250{,}000}{2500} = 100$$

$$Length\ of\ order\ cycle\ time = \frac{250\ days\ in\ a\ year}{100\ orders} = 2.5\ days$$

Example 9.4.2

Assume that it costs BestBuy $625 each time it places an order with a manufacturer for a specific model of laptop. The cost of carrying one laptop in inventory for a year is $130. The store manager estimates that total annual demand for the laptops will be 1500 units, with a constant demand rate throughout the year. The store policy is never to have stockouts of the laptops. The store is open for business every day of the year except Christmas Day.

Determine the following:

a. Optimal order quantity per order

b. Minimum total annual inventory costs

c. The optimal number of orders per year

d. The time between orders (in working days)

Solution

$D = 1500$
$S = \$625$
$H = \$130$

a. $Q^* = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(1500)(625)}{130}} = 120.1$

b. $TC(Q) = \frac{SD}{Q} + \frac{HQ}{2} = \frac{625 \times 1500}{120.1} + \frac{130 \times 120.1}{2} = \$15{,}612.49$

c. $\frac{D}{Q} = \frac{1500}{120.1} = 12.49$ orders

d. $\frac{364}{12.49} = 29.14$ days

Example 9.4.3

The Modern Furniture Company purchases upholstery material from textile supplier in Halifax, Canada. The company uses 45,000 yards of material per year to make sofas. The cost of ordering material from the textile company is $1500 per order. It costs Modern Furniture $0.70 per yard annually to hold a yard of material in inventory. Determine:

a. The optimal number of yards of material Modern Furniture should order

b. The minimum total inventory cost

c. The optimal number of orders per year, and

d. The optimal time between orders

Solution

$D = 45{,}000$
$S = \$1500$
$H = \$0.70$

a. $Q^* = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(45000)(1500)}{0.70}} = 13{,}887.3$ yd

b. $TC(Q) = \frac{SD}{Q} + \frac{HQ}{2} = \frac{1500 \times 45000}{13887.3} + \frac{0.7 \times 13887.3}{2} = \$9721.11$

c. $\frac{D}{Q} = \frac{45000}{13887.3} = 3.24$ orders per year

d. $\frac{365}{3.24} = 112.6$ days

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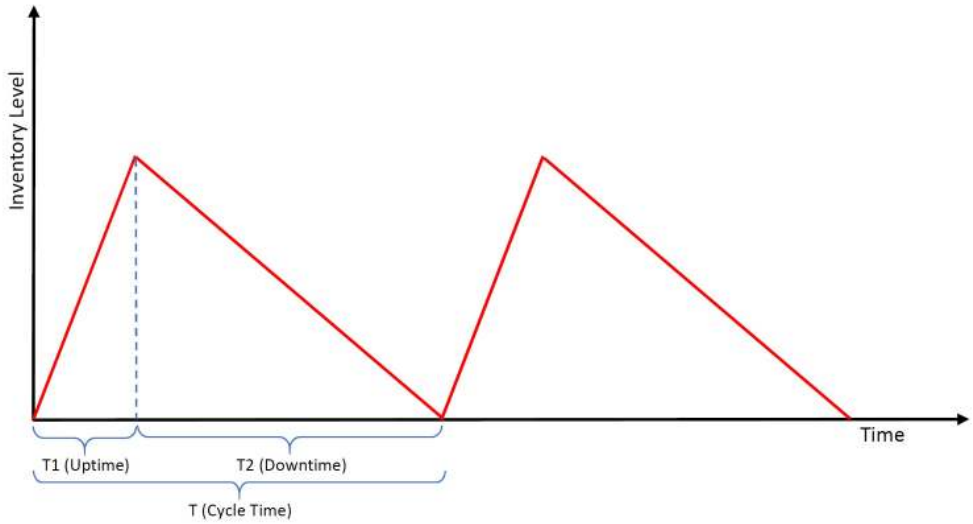
9.5: Inventory Models for Certain Demand- Economic Production Quantity (EPQ)

The second model that we have for certain or known demand scenarios is called Economic Production Quantity. In this model, we do not order from an outside supplier. Instead, we have our own production. As a result, we have a production setup cost since we will need to setup the machines or the production area before the start of the production in each cycle. In addition, having a production makes receiving of the items in our stock more gradual. This is as opposed to the sudden receiving of Q units in the EOQ model. Thus, there is a slight change to the formulations compared to the EOQ model. The following graph shows how the inventory level changes through time in the EPQ model:



The red line is showing the inventory level. During the uptime or run time (T1) we are running the production with a rate of p per day while the demand is happening with a rate of d per day. As a result, the inventory level increases with a rate of $p - d$. We continue the production until our inventory is piled up to a certain maximum level. Then, we stop the production, and only use the piled-up inventory to satisfy the customer demand. This period is called downtime (T2). The basic assumption here is that the production rate is larger than the demand rate. Otherwise, we will always have a shortage.

In terms of calculations, if we use the following notation and replace the H (i.e., the holding cost per unit of item per year) by it, we can use the same formulations from the EOQ model for the optimal lot size (run size) and the total cost. Here are the calculations:

$$H' = H\left(1 - \frac{d}{p}\right)$$

$$EPQ = Q^* = The\ optimal\ production\ lot\ (run)\ size\ in\ each\ cycle$$

$$EPQ = Q^* = \sqrt{\frac{2DS}{H'}} = \sqrt{\frac{2DS}{H\left(1 - \frac{d}{p}\right)}}$$

$$T_1 = Uptime\ or\ production\ time = \frac{Q^*}{p}$$

$$T = Cycle\ time = \frac{Q^*}{d}$$

$$T_2 = Downtime = T - T_1$$

$$TC(Q) = Total\ cost\ of\ production\ setup\ and\ inventory\ holding\ associated\ with\ a\ production\ lot\ size\ of\ Q$$

$$TC(Q) = S \times \frac{D}{Q} + \frac{Q}{2} \times H' = S \times \frac{D}{Q} + \frac{Q}{2} H\left(1 - \frac{d}{p}\right)$$

$$Maximum\ Inventory = Q^*\left(1 - \frac{d}{p}\right)$$

Note that "*D*" is defined as the demand per year, while "*d*" is the demand per day. In addition, Q* is a specific value for Q, which is associated with the optimal quantity. If we need to find the optimal total cost, we will need to use the value of Q* as the Q in the formula for TC(Q). Let's have a look at an example.

Example 9.5.1

An automotive manufacturer uses 48,000 M1 gearboxes per year for its X1 SUV series. The firm makes its own M1 gearboxes, which it can produce at a rate of 800 per day. Carrying cost is $1 per gearbox per year. Setup cost for a production run of M1 gearboxes is $45. The firm operates 240 days per year. Determine:

a. the optimal run size,

b. the minimum total annual cost for carrying and setup,

c. cycle time for the optimal run size,

d. the production run time (uptime), and

e. maximum inventory.

Solution

Demand per year = $D = 48000$
Production rate per day = $p = 800$
Demand rate per day = $d = 48000 \div 240 = 200$
Ordering cost per unit = $S = \$45$
Unit inventory holding cost = $H = \$1$

$$H' = H(1 - d/p) = 1 \times (1 - \frac{200}{800}) = 0.75$$

(a) the optimal run size

$$Q^* = \sqrt{\frac{2SD}{H'}} = \sqrt{\frac{2 \times 45 \times 48000}{0.75}} = 2400$$

(b) the minimum total annual cost for carrying and setup

$$TC(Q^*) = S \times \frac{D}{Q^*} + H' \times \frac{Q^*}{2} = 45 \times \frac{48000}{2400} + 0.75 \times \frac{2400}{2} = 1800$$

(c) cycle time for the optimal run size

$$T = \frac{Q^*}{D} = \frac{2400}{48000} = 0.05 \text{ year} = 0.05 \times 240 = 12 \text{ days}$$

(d) the production run time (uptime)

$$T_1 = \frac{Q^*}{p} = \frac{2400}{800} = 3 \text{ days}$$

(e) maximum inventory

$$I_{max} = Q^*(1 - \frac{d}{p}) = 2400 \times (1 - \frac{200}{800}) = 1800$$

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CHAPTER OVERVIEW

10: Just in Time Lean Systems

Would you order a delivery pizza for dinner from a restaurant advertising delivery in 6 hours? How about a restaurant that can bring you a cold, stale pizza in only 5-minutes? To meet the consumer's needs, the pizza shop must be able to give customers the number of pizzas they want when they want it. Preparing pizzas in advance is too wasteful because most consumers are not likely to buy a stale pizza. Meanwhile, if you take too long to deliver the pizza, you will lose customers to a more responsive competitor. The concept of just-in-time focuses on making what you need to meet customer demand only when you need it. For a pizza delivery shop, that probably means a fresh pizza at the customer's door in around 30 minutes. This philosophy can apply to a range of operations, from simply washing a car to manufacturing a complex aircraft.

Similarly, the concept of lean manufacturing refers to eliminating waste in the manufacturing process. The Toyota Product System is the model for modern manufacturers that want to control waste. In this unit, we will look at seven types of waste and processes for controlling them. In addition, we will explore the origins of the "Just-in-Time" (JIT) philosophy and the use of pull systems to control inventory.

10.1: Lean Manufacturing and Control

10.2: Five Core Principles of Lean

10.3: Just-In-Time (JIT) Systems

10.4: Total Quality Management

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10.1: Lean Manufacturing and Control

Lean control, or simply lean, has become an immensely popular business control and improvement methodology in recent years. Lean control is a highly refined example of nonfinancial controls in action. Lean is a system of nonfinancial controls used to improve product and service quality and decrease waste. Lean was initially focused on improving manufacturing operations but is now used to improve product development, order processing, and a variety of other nonmanufacturing processes (sometimes called "lean in the office").

Lean's popularity has both resulted from, and been driven by, an explosion in the volume of lean-related educational resources. Amazon offers almost 1,800 books and other materials about lean, and Yahoo! hosts over 90 online discussion groups relating to lean. Colleges and universities, industry trade associations, and private consulting firms routinely offer courses, seminars, and conferences to explain what lean is and how to use it.

Lean control is a number of things. According to James Womack, "it is a process for measuring and reducing inventory and streamlining production. It is a means for changing the way a company measures plant performance. It is a knowledge-based system. It takes years of hard work, preparation and support from upper management. Lean is so named because it purports to use much less of certain resources (space, inventory, workers, etc.) than is used by normal mass-production systems to produce comparable output." The term came into widespread use with the 1990 publication of the book *The Machine That Changed the World*, by James P. Womack, Daniel T. Jones, and Daniel Roos. [1]

Lean will always be associated with Toyota Motor Corporation because most lean tools and techniques were developed by Toyota in Japan beginning in the 1950s. After World War II, Toyota's leaders were determined to make the company a full-range car and truck manufacturing enterprise, but they faced several serious challenges. The Japanese motor vehicle market was small and yet demanded a fairly wide range of vehicle types. This meant that Toyota needed to find a way to earn a profit while manufacturing a variety of vehicles in low volumes. In addition, capital was extremely scarce, which made it impossible for Toyota to make large purchases of the latest production equipment. To succeed, or even survive, Toyota needed a way to build vehicles that would require fewer resources. To achieve this goal, Toyota's leaders, principally Eiji Toyoda and Taiichi Ohno, began to create and implement the production techniques and tools that came to be known as lean.

To gain the most benefits from lean, managers must be able to determine what specific lean tools and techniques will be effective in their particular business. And to make that determination, they must clearly understand what lean is designed to accomplish (its primary objectives) and what core principles lean is based on. With this understanding, managers can decide which lean tools will work well in their business, which lean tools will need to be modified or adapted to work well, and which tools are simply not appropriate.

What, then, are the major objectives and core principles of lean? Despite the arguments and debates that often surround attempts to define and describe lean, it is clear that the ultimate objective of lean is the avoidance of *muda*, or wasteful activity, in all business operations. Muda comprises seven deadly wastes. In the lean world, waste means any activity or condition that consumes resources but creates no value for customers. Therefore, seven deadly wastes include the following:

1. **Defects** prevent the customer from accepting the product produced. The effort to create these defects is wasted. New waste management processes must be added in an effort to reclaim some value for the otherwise scrap product.
2. **Over-production** is the production or acquisition of items before they are actually required. It is the most dangerous waste of the company because it hides the production problems. Over-production must be stored, managed, and protected.
3. **Transportation** is a cost with no added value. In addition, each time a product is moved it stands the risk of being damaged, lost, and delayed. Transportation does not transform the product in any way that the consumer is willing to pay for.
4. **Waiting** refers to both the time spent by the workers waiting for resources to arrive, the queue for their products to empty as well as the capital sunk in goods and services that are not yet delivered to the customer. It is often the case that there are processes to manage this waiting.
5. **Inventory** in the form of raw materials, work-in-progress, or finished goods represents a capital outlay that has not yet produced an income either by the producer or for the consumer. Any of these three items not being actively processed to add value is waste.

6. **Motion** refers to the actions performed by the producer, worker, or equipment. Motion has significance to damage, wear, and safety. It also includes the fixed assets and expenses incurred in the production process.
7. **Over-processing** is defined as using a more expensive or otherwise valuable resource than is needed for the task or adding features that are designed for but unneeded by the customer. There is a particular problem with this item regarding people. People may need to perform tasks that they are overqualified for to maintain their competency. This training cost can be used to offset the waste associated with over-processing.

References

1. Womack, J. P., Jones, D. T., & Roos, D. (1990). The machine that changed the world. New York: Rawson Associates, 1990.

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10.2: Five Core Principles of Lean

Lean methodologies are lean because they enable a business to do more with less. A lean organization uses less human effort, less equipment, less facilities space, less time, and less capital—while always coming closer to meeting customers' exact needs. Therefore, lean is not just another cost-cutting program of the kind we often see in business organizations. Lean is much more about the conservation of valuable resources than it is about cost cutting.

In their best-selling book, Lean Thinking, James Womack and Daniel Jones identified five core principles of lean.[1]

Let's examine them one by one:

Define Value from the Customer's Perspective

The first core principle in the Womack/Jones lean framework is that value must be defined and specified from the customer's perspective. While this seems simple enough, it requires much more than high-sounding, generic statements. To be meaningful, value must be defined in terms of specific products. This means that managers must understand how each specific product meets the needs of specific customers at a specific price and at a specific time.

Describe the Value Stream for Each Product or Service

The second core principle of lean is to describe the value stream for each product or service (or, in some cases, for groups or families of similar products). The value stream is the set of activities that the business is performing to bring a finished product to a customer. It includes both direct manufacturing activities and indirect activities such as order processing, purchasing, and materials management. Developing a detailed description or map of each value stream usually reveals huge amounts of waste. It enables managers to identify which value stream activities add value to the product, which activities add no value but cannot be immediately eliminated for various reasons, and which activities create no value and can be immediately eliminated (or at least reduced substantially).

Create Flow in Each Value Stream

The third essential principle of lean is embodied in the word flow. When a value stream has been completely described as unnecessary, non-value-adding activities have been eliminated, the basic idea of flow is to arrange the remaining activities sequentially, so that products will move smoothly and continuously from one activity to the next. However, flow means more than ease of movement. Flow is the lean principle that directly challenges the traditional "batch-and-queue" model of manufacturing, where people and equipment are organized and located by function, and products (and component parts) are manufactured in large batches. Lean organizations strive to improve flow by reducing the size of production batches, and in the process, they increase flexibility and lower costs.

Produce at the Pace (Pull) of Actual Customer Demand

Producing at the pace or pull of actual customer demand is the fourth key principle of lean. One of the greatest benefits of moving from traditional batch-and-queue manufacturing to continuous flow production is that lead times fall dramatically. Reduced lead times and increased flexibility mean that lean organizations can respond to actual customer demand rather than attempt to predict in advance what that level of demand will be. This allows lean organizations to substantially lower both finished goods and work-in-process inventories.

Strive to Continuously Improve All Business Operations

The fifth core principle of lean is continuous improvement, expressed in Japanese by the word kaizen. Companies that implement lean adopt the mind-set that it is always possible to improve any business activity, and they regularly conduct kaizen events throughout their organizations to improve specific processes or operations. Today, Toyota is recognized as one of the most "lean" business enterprises in the world. Even more daunting, and humbling, is the fact that Toyota is still striving to improve.

References

1. Womack, J. P., & Jones, D. T. (2003). Lean thinking. New York: Simon & Schuster

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10.3: Just-In-Time (JIT) Systems

Just-in-time (JIT) is a management philosophy that originated in the 1970s. Taiichi Ohno is credited with developing JIT and perfecting it for Toyota's manufacturing plants in Japan. The main goal of JIT is to eliminate anything that does not add value from the customer's perspective. Non-value-added activities are referred to as "waste" in JIT. Examples of waste include:

- overproduction beyond what is needed to satisfy immediate demand
- waiting time (work-in-process, customer waiting)
- unnecessary transportation (material handling, customer travel through a facility, etc.)
- processing waste (yield rates, start-up costs)
- inventory storage waste (space, deterioration, obsolescence, etc.)
- unnecessary motion and activity (waste in work techniques, etc.)
- waste from product and service defects (rework, scrap, warranty, etc.)

There are three essential elements that contribute to the successful practice of JIT:

- JIT manufacturing principles
- Total Quality Management (TQM)
- employee empowerment

JIT Manufacturing Principles

There are several JIT principles that are applied in a manufacturing setting. The following are some of these main principles:

- Inventory reduction to expose waste
- Use of a "demand-pull" production system
- Quick setups to reduce lot sizes
- Flexible resources
- Cellular layouts

Inventory reduction to expose waste

Inventory covers up a lot of wasteful practices (poor equipment, weak vendors, bad quality, long setup times, etc.). By gradually lowering inventory, the weaknesses of the production system can be revealed and addressed one by one. Machines can be replaced or better maintained, vendors quality and delivery can be improved, machine setup procedures can be streamlined, quality practices can be implemented, and labor and equipment can be laid out more efficiently. These improvements allow the organization to operate with less inventory, less costs, and faster response times in meeting customer needs.

Demand-pull production system

The traditional approach to manufacturing management promotes a strong focus on machine and labor utilization. The view was that if managers make sure that workers and machines are always busy, then surely, the factory will be productive and efficient. This approach is called the "push" system of manufacturing, where raw material and work-in-process are continuously pushed through the factory in the pursuit of high utilization. The problem with this approach is that it usually produces high levels of inventories, long lead times, overtime costs, high levels of potential rework, and workers who are competing with one another rather than working cooperatively.

In contrast to the push system, JIT applies a "demand-pull" system that operates on the rule that work should flow to a work center only if that work center needs more work. If a work center is already occupied with work activity, the upstream work center should stop production until the downstream work center communicates a need for more material. The emphasis on maintaining high utilization is removed in a JIT environment. The focus of a JIT environment is on addressing the challenges that affect the overall effectiveness of the factory in meeting its strategic goals (setup time reduction, quality improvement, enhanced production techniques, waste elimination, etc.), rather than allowing excess inventory to cover up inefficiencies that reduce the factory's competitiveness.

One of the tools that is used in JIT systems to facilitate the pull system and coordinate activities (such as picking up a new raw material or work-in-process or the production itself) between different workstations is called Kanban. Kanban is a ticket or signal

that is given from one part of the process to another part to let them know that they are allowed to start their next activity. This supports the very concept of pull production and avoiding the waste by not doing things at the time that they are not needed. Kanban is also a signboard which is used to organize what needs to be done, what is under progress and what is done. This aspect of Kanban has been used in Agile workflow management systems. Watch the following video to get a better sense of how the Kanban system works:

Watch on YouTube to see the transcript.

Quick setups to reduce lot sizes

The longer it takes, and the more expensive it is to setup equipment and labor to produce an item, the greater the quantity of items that have to be produced in a given production run. Traditional production management philosophy promoted the notion that long production runs of the same item were the key to driving down unit costs. The problem was that large production runs created large quantities of WIP and finished goods inventory that far exceeded the demand. These items would consequently cause high levels of inventory costs, long lead times, high potential rework, low flexibility in responding to customer needs, etc.

Driving down setup costs and setup times are key to dramatically improving factory competitiveness in a JIT environment. In the 1980s, the 3M company converted a factory that made a few adhesive products in long production runs into a factory that made over 500 adhesive products in small production runs. To keep unit production costs under control, 3M studied the setups on its coating machines. Since the cost of chemical waste disposal was a major part of the cost of changing over a coating machine to make another product, 3M shortened the length of hoses that needed purging and redesigned the shape of the adhesive solution holding pan on the coating machine to be shallower. 3M also used quick-connect devices, disposable filters, and work teams to speed up setups. The result was that 3M could maintain low unit costs on its coating machines while producing small lots of hundreds of products to meet market demand quickly.

Flexible resources

The enemy of JIT is uncertainty. A JIT environment thrives on predictability in customer demand, production processes, suppliers, and workers. Of course, uncertainty cannot be completely eliminated in most organizational environments.

The defense against uncertainty that cannot be driven out is to implement flexible resources that can adapt easily to changing circumstances. General-purpose, moveable equipment that can fulfill a wide variety of production requirements is one way to improve flexibility. For example, drilling machines with quick-change bits which can be wheeled into position to form new work cells allow the factory to maximize efficiency while producing exactly what is needed to satisfy immediate demand. Another example is Toyota's use of paint canisters that attach to paint sprayers. Any car can be painted any color without having to purge hoses in switching from one color to another.

Multifunctional workers are another way to bring flexibility to the work environment. At Honeywell's heating and cooling controls plant, workers are trained to operate all the machines on their work line. The flexibility that comes from multifunctional workers changes the nature of how work gets done. Instead of workers being trained on one machine and working independently of one another, multifunctional workers have a "big picture" view of the production line, where every worker understands all aspects of the line and how to work together to meet quality and schedule goals regardless of the circumstances.

Cellular flow layouts

Cellular layouts promote JIT goals by featuring unidirectional product flows, high visibility, and fast throughput times. Workers with multifunctional skills are assigned to individual cells and have responsibility and control of the products they produce. Workers in a cell environment tend to have a greater sense of ownership and pride in their work because they have a "big picture" view of the product as it is converted from raw material to a finished good. This deeper understanding of the production process increases the opportunities for workers to contribute ideas for process improvements.

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10.4: Total Quality Management

TQM was discussed in detail earlier. TQM goes hand in hand with the JIT philosophy because quality is a major source of uncertainty and non-value-added activities in an organization with poor quality practices. TQM promotes continuous improvement, doing it right the first time, designing quality into products and processes, and establishing an overall focus on prevention as the primary quality activity.

Employee empowerment

Front-line employees play a critical role in successful JIT practices. They work in partnership with management and each other in the continuous pursuit of excellence. There are several ways in which front-line employees contribute to JIT success:

- Employees work together in problem-solving teams to gather data and build consensus on how to improve work processes.
- Employees are responsible for understanding the quality measures of their work and what they need to do to meet the needs of internal and external customers.
- Each employee is empowered to take action to correct problems.
- Employees have cross-functional skill sets that allow them to be assigned to areas which need help, and to help them adopt a broader (“big picture”) view of the production process.
- Unlike a traditional “push” environment where line workers are relatively independent of one another in their work activities, JIT employees are connected by the “demand pull” discipline, where work is not produced unless the downstream work center needs it. Demand-pull promotes the inter-connectedness of workers.
- Front-line employees are responsible for the basic maintenance of their machines. This helps employees have a better understanding of the condition of their equipment and its ability to meet quality and production requirements.

Management works with employees by being coaches and facilitators rather than authoritative supervisors. Managers are charged with hiring employees who can work in a proactive team environment, and provide the training and incentives to build a work culture that is focused on continuous improvement.

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