

Operations Management

OPERATIONS MANAGEMENT

AZIM ABBAS AND SEYED GOOSHEH

Fanshawe College Pressbooks
London Ontario



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ACKNOWLEDGEMENTS

This open textbook has been compiled and adapted by Azim Abbas & Seyed Goosheh in partnership with the [OER Design Studio](#) and the Library Learning Commons at [Fanshawe College](#) in London, Ontario.

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ABOUT THIS BOOK

Operations Management introduces readers to the core principles and practices that drive efficient, effective production and service delivery. Through real-world examples, clear explanations, and interactive resources, this open textbook explores topics such as process design, capacity planning, supply chain management, quality control, and lean systems. Designed for college-level learners, it connects operational decisions to strategic business outcomes, emphasizing practical tools for continuous improvement and performance excellence.

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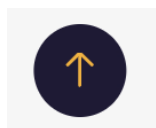
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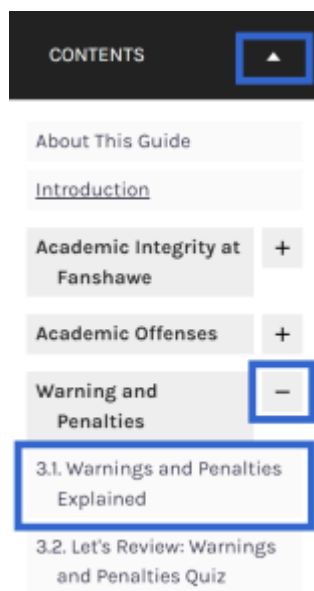
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CHAPTER 1: INTRODUCTION TO OPERATIONS MANAGEMENT

Chapter Overview

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1.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Explore the key current trends in Operations Management.
- Define operations management and its core functions within a business.
- Explain the role of operations management in transforming inputs (materials, labour) into outputs (goods, services) for a business.
- Explain why a business student should study Operations Management.
- Identify some of the Professional Organizations involved in Operations Management.
- Describe the phases of Operations Management history.
- Discuss how producing goods is different from performing services.

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1.1 OPERATIONS MANAGEMENT

Operations Management and Everyday Life

Although Operations Management is often taught in business schools, one can skip business school to relate to this topic. Perhaps we can learn it by looking at the everyday life of a family living in London, Ontario.



Figure 1.1.1: “Operations Management in Everyday Life, London, Ontario” by Sanaz Habib, [CC BY-SA 4.0](#)

To conduct what we refer to as everyday life, they would need to do weekly grocery shopping to buy milk, meat, bread, fruit and vegetables and a few other necessities. Now, let us focus on the bread they are buying. It turns out that that bread was brought to that store in a truck from a bakery that relies on a mill to supply it with flour, which comes from a farm. The kids would have to go to school on a school bus that needs to pick them up and bring them home every day. Mom and Pop would go to work in their cars, which they had bought from a dealership and supplied by auto manufacturers. These cars needed to be maintained by a mechanic in a garage who would rely on parts and supplies delivered to his garage. The family needs to handle their finances using a bank, their garbage has to be handled by the city, and when they are ill, they need the service of a medical facility. Are these the only things this family needs to manage their daily life? Certainly not! Now, let us return to the bread they buy from their grocery store. Like you and I, they do not care “how” that loaf of bread was made available, but they certainly know “what” they need, in this case, a loaf of bread. If we want to connect the “what” to “how,” we are stepping into the field of operations management.

Operations management is a discipline that involves the processes of converting inputs into goods and

services, creating value for customers. It is the foundation for any organization, ensuring efficient resource utilization in producing the products we rely on daily.

What is Operations Management

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

Every day, you use a multitude of physical objects and a variety of services. Most physical objects have been manufactured, and most of the services are 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 you buy and consume daily are produced.

The following video shows some of the basic strategic areas in operations management. We will cover some of these areas in addition to some tools and techniques used in operations management.

Video: “[Operations Management](#)” by [Skillsoft YouTube](#) [3:12] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Producing Goods and Services

In the production of goods, the result is the creation of tangible products such as vehicles, articles of clothing, cell phones, or shovels. On the other hand, a service is intangible, such as a car repair, haircut, or medical treatment.

In operations management, both the production of goods and the delivery of services play crucial roles. However, there are significant differences between the two.

1. *Nature of Output:*

- Goods: Tangible products like vehicles, clothing, cell phones, and shovels.
- Services: Intangible offerings such as car repairs, haircuts, and medical treatments.

2. *Customer Interaction:*

- Services involve more direct customer contact. Customers either visit the service provider or vice versa.
- In manufacturing, customers rarely visit the production facility; purchases occur elsewhere.

3. *Labour Content:*

- Services typically require more labour than manufacturing organizations.

4. *Input Variability:*

- Services face greater input variability due to unique customer circumstances.
- Manufacturing companies deal with more standardized inputs.

5. *Quality Measurement:*

- Manufacturing quality assessment is technical and straightforward.
- The perception of service quality depends on various factors.

6. *Productivity Measurement:*

- Manufacturing productivity is easier to measure due to standardization.
- Services pose challenges in productivity measurement.

7. *Inventory Handling:*

- Manufacturing can store unsold goods for later sale.

- Services lack this option; once the time passes, the capacity is lost.

Figure 1.1.1 Image Sources

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1.2 TRANSFORMATION PROCESSES

Video: “[What is Operations Management?](#)” by [Frankfurt School of Finance & Management](#) [1:35] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

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).

Organizations often need to transform three types of input: materials, information, and customers. For instance, withdrawing money from a bank account involves handling information related to the customer’s account, physical materials like cheques and currency, and the customer. Similarly, providing medical treatment to a patient in a hospital requires considering the patient’s health status (the ‘customer’), the materials used in treatment, and relevant patient information.

These transformation processes can be grouped into four categories (Figure 1.2.1):

- **Manufacture:** This involves physically creating products, such as automobiles.
- **Service:** Service-oriented processes focus on treating customers or storing products, as seen in hospitals or warehouses.
- **Supply:** This category encompasses changes in ownership of goods, often observed in retail settings.
- **Transport:** Processes related to the movement of materials or customers, such as taxi services.

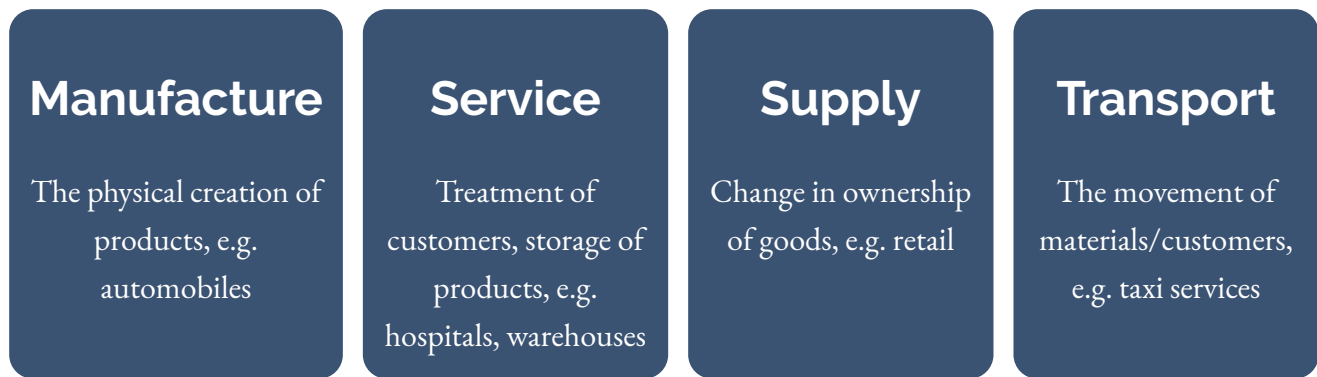


Figure 1.2.1: Categories of transformation processes.

Several different transformations are usually required to produce a good or service. The overall transformation can be described as the **macro-operation**; the more detailed transformations within this macro-operation are **micro-operations**.



Example

For example, the macro-operation in a brewery is making beer, and the micro-operations involved in beer production are (Figure 1.2.2):

- *Milling*: Grind malted barley into grist.
- *Mashing*: Mix the grist with hot water to create wort.
- *Fermentation*: Add yeast to the wort and ferment it into beer.
- *Cooling and Transfer*: Cool the wort and transfer it to the fermentation vessel.
- *Filtering*: Remove spent yeast from the beer.
- *Packaging*: Decant the beer into casks or bottles.

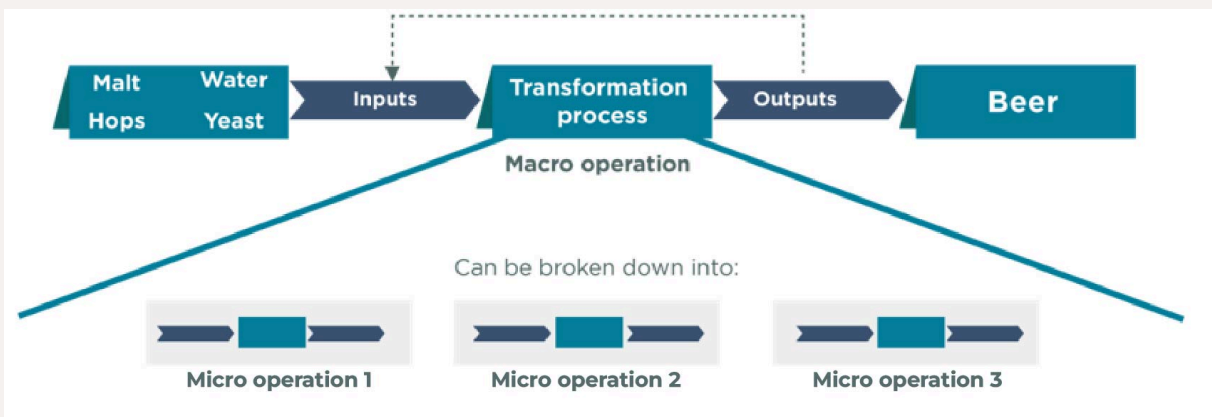


Figure 1.2.2: “[Macro and Micro Operations \(transformation processes\)](#)” by [The Open University](#), [CC BY-NC-SA 4.0](#). Mods: re-coloured by Fanshawe College

Image Description

A flowchart that illustrates the beer production process as a transformation system. Inputs—malt, hops, water, and yeast—enter the transformation process. The process, shown as a macro operation, produces the output of beer. The macro operation can be further divided into multiple micro operations, represented as three sequential process boxes labelled “Micro operation 1,” “Micro operation 2,” and “Micro operation 3.”

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1.3 THE OPERATIONS FUNCTION

Regardless of whether it explicitly labels it as ‘operations,’ every organization has a fundamental function related to producing goods and services. This involves resource procurement, conversion into outputs, and distribution to users. **Operations** encompasses all activities necessary for delivering an organization’s goods or services to customers and clients.

In large and complex organizations, operations is a critical functional area. Designated individuals manage various aspects of the organization’s operational processes. The effectiveness of operations significantly impacts customer satisfaction. For private-sector companies, the operations function aligns with profit, growth, and competitiveness, while public and voluntary organizations focus on delivering value for money.



Examples

Some examples to illustrate the concept of operations within organizations:

- **Manufacturing Company:** A manufacturing company produces automobiles. Its operations involve sourcing raw materials (such as steel, plastic, and electronics), assembling components, and delivering finished cars to dealerships.
- **Retail Chain:** A retail chain operates multiple stores. Its operations include inventory management, restocking shelves, handling customer transactions, and ensuring a smooth checkout process.
- **Healthcare Facility:** A hospital's operations encompass various functions, such as patient admissions, medical treatments, laboratory testing, and maintaining medical records.
- **Online Marketplace:** An e-commerce platform manages operations related to product listings, order processing, payment gateways, and logistics for shipping products to customers.
- **Service-Based Organization:** A consulting firm's operations involve client engagement, project management, resource allocation, and delivering high-quality consulting services.

Operations management is concerned with designing, managing, and improving 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 fundamental functional areas: operations, marketing and sales, finance, and human resources. Operations directly produce the product or service that customers pay for, while the other three departments provide support to ensure smooth business operations.

Marketing: The Voice of the Customer

Marketing acts as the bridge between customers and operations. They ensure the company creates products or services that fulfill customer needs and desires. They identify the most valued features and benefits, keeping operations on the right track.

Finance: The Engine that Keeps Things Running

Finance is the lifeblood of the company. They manage the money flow, ensuring there's enough to cover everything from materials and payroll to equipment upgrades. This allows operations to run smoothly without disruptions.

Human Resources: Building the Dream Team

HR is the foundation of any successful organization. They recruit, hire, and train the talented individuals who make up the operations team. They handle everything from compensation and benefits to ensuring a smooth succession plan and guaranteeing a skilled workforce for the future.

Business Functions of Departments

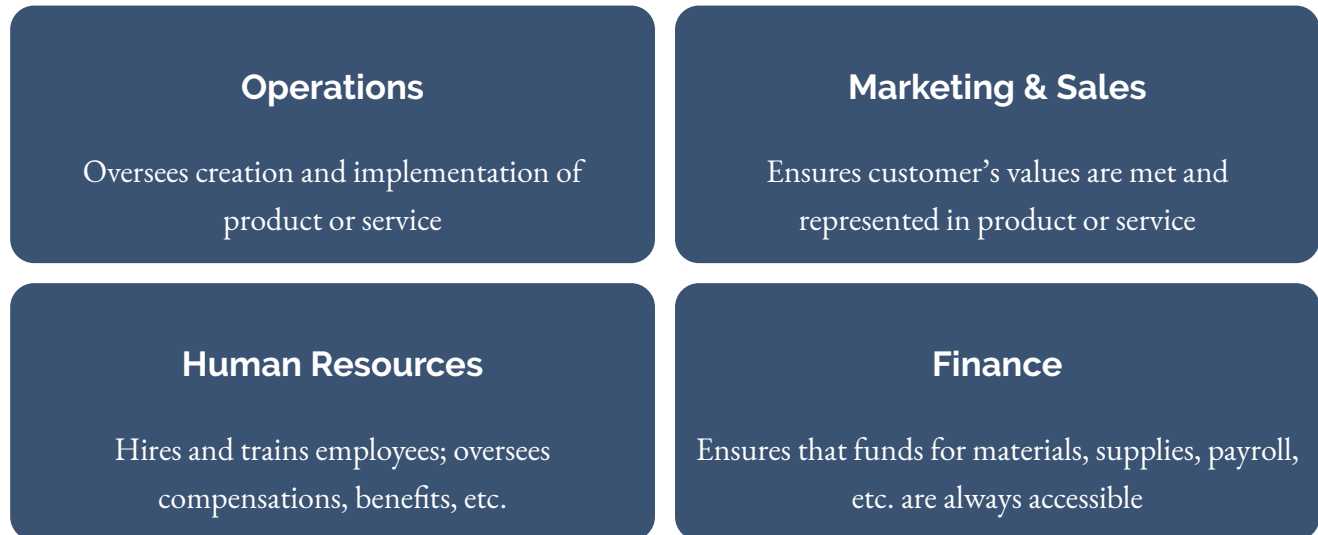


Figure 1.3.1: Business functions of departments.

1.4 WHY STUDY OPERATIONS MANAGEMENT?

In most organizations, operations tend to be the largest department in terms of the number of employees. If you're a recent graduate, consider starting your career in a company's operations department. A career in operations can provide more job openings than smaller departments. Larger companies can provide more growth opportunities as well. You can focus on finding a great company culture and worry less about the specific job title. With a good work ethic (punctuality, energy, and proactiveness), you can likely get promoted to your desired role later.



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Operations: The Engine of the Business

Operations play a critical role in any organization:

- **Cost Center:** This department spends a significant portion of the company's budget, making it a central focus for leadership.
- **Interconnectedness:** All departments (finance, marketing, HR) interact with operations regularly. Understanding the core processes, regardless of your department, is valuable.
- **Innovation Hub:** Major breakthroughs often happen in operations. Companies like Toyota, Amazon, and Dell achieved success through innovative operational practices.

What is Operational Innovation?

It's about finding new ways to run the business – fulfilling orders, developing products, providing customer service, and more.

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

- **Effectiveness:** It's about doing the right things. This means making choices and taking actions that benefit the business and, most importantly, add value for the customer. Think of it as picking the

winning strategy.

- **Efficiency:** It's about doing things well but without wasting resources. This means finding ways to streamline tasks and avoid unnecessary steps that cost time or money. Think of it as getting the job done smartly.

In short, businesses want to do the right things (effectiveness) in the best way possible (efficiency).

Many decisions involve a trade-off between effectiveness and efficiency. For instance, consider hiring an additional full-time server in a restaurant. While this may lead to faster service and a more attentive customer experience, it also comes with higher costs, reducing overall efficiency.

Value, in this context, relates to the balance between quality and price. We create value if we can offer customers a higher-quality product at the same price. Similarly, providing the same product at a lower price benefits the customer.

Resources for Operations Management Learners and Professionals

- 
- [Supply Chain Management Association \(SCMA\)](#)
 - [National Institute of Supply Chain Leaders \(former SCMAO\)](#)
 - [Canadian Institute of Traffic and Transportation \(CITT\)](#)
 - [Association for Supply Chain Management \(APICS\)](#)
 - [American Society for Quality \(ASQ\)](#)
 - [Project Management Institute \(PMI\)](#)

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1.5 DEVELOPMENT OF OPERATIONS MANAGEMENT

Operations in some form have been around as long as human endeavour 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.

Craft Manufacturing: The Hands-On Era

Imagine skilled artisans meticulously building furniture or clocks. That's craft manufacturing in a nutshell. This system, where craftspeople made unique products for individual customers, thrived for centuries. Skills were passed down through apprenticeships, and workshops buzzed with activity. While ideal for small-scale production, it struggled with competition in a growing world.

Mass Production: The Age of Efficiency (1910 – 1980)

The 19th century ushered in a revolution: mass production. Here, the focus shifted to churning out large quantities of standardized goods at lower costs. Think assembly lines and interchangeable parts. This innovation came with a trade-off – less variety for consumers who got what was offered.

Key innovations of mass production:

- *Standardized parts*: Imagine car parts fitting seamlessly across models. This American system streamlined production and reduced costs.
- *Scientific Management*: Frederick Taylor aimed to find the “one best way” to complete tasks, breaking them down for maximum efficiency. This approach, while efficient, raised concerns about worker well-being.
- *The Assembly Line*: Henry Ford perfected this concept, bringing the product (cars) to the workers, further boosting production speed and lowering costs.

The Modern Period: Adapting to Change (1995 – 2015)

By the 1970s, mass production began to show its limitations. Consumer preferences were diversifying, and markets were changing rapidly. Enterprising Japanese manufacturers challenged the status quo with innovative approaches like Total Quality Management (TQM) and Just-in-Time (JIT) production, emphasizing quality and efficiency.

Modern Manufacturing Paradigms

Several popular models have emerged in this era:

- *Flexible Specialization*: Small firms collaborate in networks to focus on specific stages of production, creating a whole product. This requires strong communication and long-term partnerships.
- *Lean Production*: Inspired by Toyota's success, this approach eliminates waste and minimizes inventory, leading to faster production and lower costs.
- *Mass Customization*: Imagine getting a customized product at mass-produced prices. This concept is becoming a reality with advancements in technology and automation.
- *Agile Manufacturing*: Rapidly adapting to shifting market demands is key here. Technology plays a crucial role in achieving this agility.

Industry 4.0 – Fourth Industrial Revolution (4IR)

According to McKinsey & Company (2024), the Fourth Industrial Revolution (4IR) builds upon the innovations of the Third Industrial Revolution, also known as the digital revolution. The digital revolution spanned from the 1950s to the early 2000s and introduced technologies like computers, the Internet, and various electronics.

Industry 4.0 takes these advancements further by leveraging four key disruptive technology categories across the entire value chain:

- *Connectivity, Data, and Computational Power*: Examples include cloud technology, the Internet, blockchain, and sensor networks.
- *Analytics and Intelligence*: This category encompasses advanced analytics, machine learning, and artificial intelligence.
- *Human–Machine Interaction*: Technologies such as virtual reality (VR), augmented reality (AR), robotics, and autonomous guided vehicles enhance interaction between humans and machines.
- *Advanced Engineering*: Additive manufacturing (such as 3-D printing), renewable energy solutions and nanoparticles contribute to cutting-edge engineering practices.

These technologies collectively drive Industry 4.0, revolutionizing how we approach manufacturing, production, and overall business processes.

In various ways, these approaches combine the high volume and low cost associated with mass production with product customization and high levels of innovation and quality associated with craft production. As technology continues to evolve, we can expect even more exciting advancements in how we make things in the future.

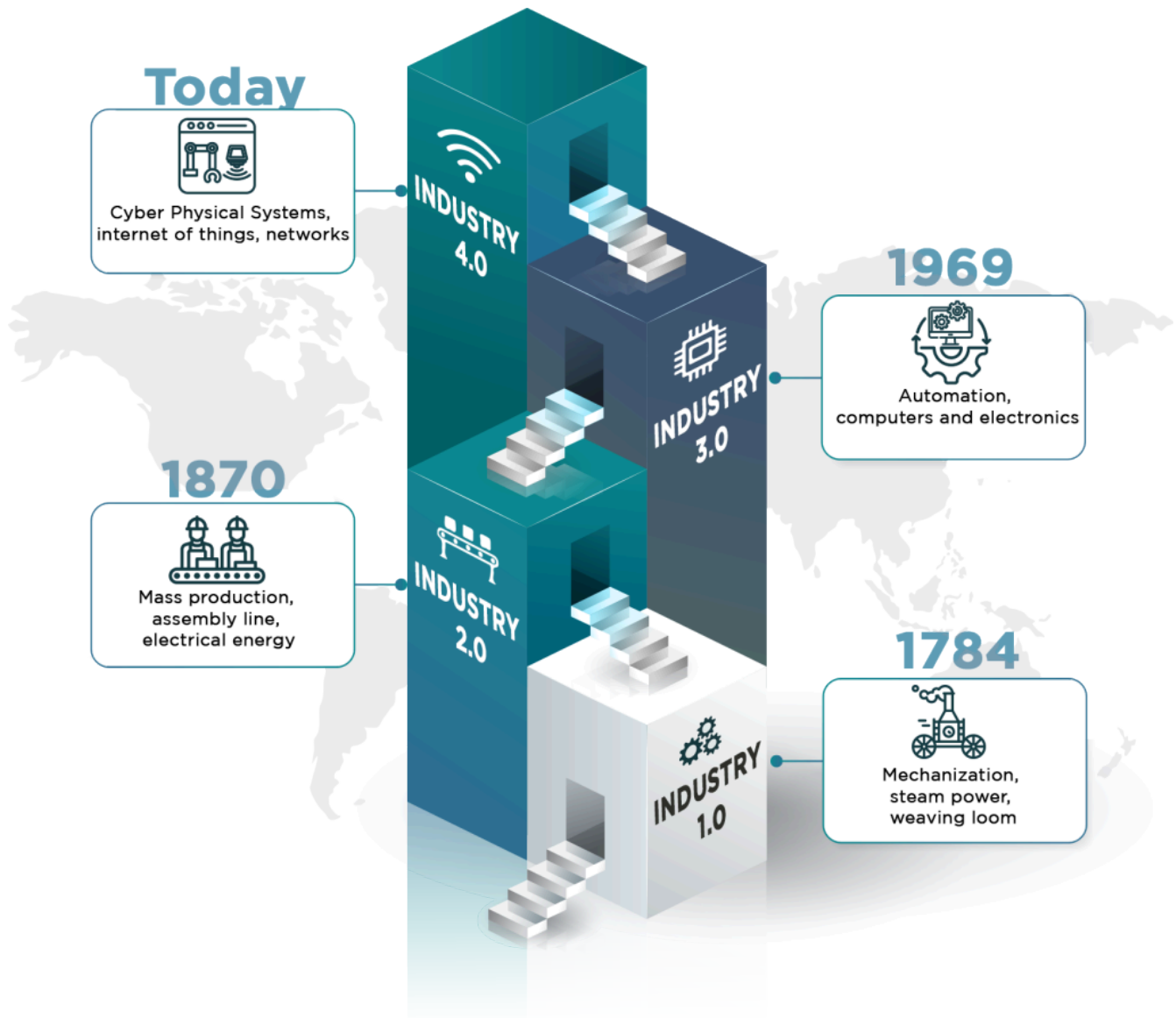


Figure 1.5.1: “Industrial Revolution” by Sanaz Habib, [CC BY-NC-SA 4.0](https://creativecommons.org/licenses/by-nc-sa/4.0/)

Image Description

An infographic depicting the evolution of industrial revolutions. It features a 3D structure with four levels. The bottom level, ‘INDUSTRY 1.0,’ dated 1784, mentions mechanization, steam power, and the weaving loom. The second level, ‘INDUSTRY 2.0,’ dated 1870, refers to mass production and electrical energy. The third level, ‘INDUSTRY 3.0,’ dated 1969, highlights automation, computers, and electronics. The top level, ‘INDUSTRY 4.0,’ dated today, includes cyber-physical systems, the internet of things (IoT), and networks.

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1.6 KEY TRENDS IN OPERATIONS MANAGEMENT

In the previous section, we looked at the evolution of operations management. Those changes largely took place in response to the business and economic changes that aimed at improving productivity through innovation in pursuit of greater economic gains. In doing so, however, the business world realized the need to balance economic and non-economic bottom lines. Such a realization created some key trends that impacted operations management.

Globalization

The economic principle of “competitive advantage” led both the public and private sectors in many countries to part from “self-sufficiency” and “protectionism” and open doors to trade. This change allowed companies to obtain their material or establish manufacturing facilities in a country at a lower cost.

Supply Chain Expansion

With larger trade volume, supply chains also expanded, making it easier for businesses to find more supply sources and/or new markets for their products. The expanded chains also made it possible to find more distributors, wholesalers, manufacturers, and other partners in the chain, such as logistics companies and warehouses. The longer supply chain allowed more companies to get involved, from providers of raw materials to the sellers of final products.

E-Commerce

Allowed businesses to sell to other businesses or customers online. As e-commerce relies on internet use, however, businesses and consumers may not use it with equal success. For example, many small businesses, which contribute significantly to almost any economy’s gross domestic product (GDP), do not use e-commerce. This is true for many consumers as well.

Technology

Information technology (IT) has played a vital role in facilitating commerce between businesses (B2B) or between businesses and consumers. An example of such impact can be found in the order-to-delivery process

in Amazon, whereby a Canadian places an order for pieces of custom-made clothing that are made in China and Brazil and has it delivered to their front door in days.

Sustainability

Aside from profit (economic gain), in the past few decades, businesses have also paid attention to social and environmental gains. Metaphorically, these three can be perceived as a tripod; if the economic leg is heavier, the tripod will become imbalanced. Therefore, such initiatives that pay closer attention to the social well-being of underpaid workers who work in sweatshops have gained a place in business practices. In addition, closer attention to “closed-loop supply chain” and “life cycle analysis” has been encouraged in product design.

Recent (Post-Covid) Trends

The COVID-19 pandemic changed business practices in many ways and created new trends in their operations. While some of the previously mentioned trends helped business companies during the Pandemic, the human/social aftermath of COVID-19 seems to have created new challenges in business operations. For example, while enhanced information technology (IT) and advances in artificial intelligence (AI) led to better digital communication and increased productivity, they also took away personal connections and led people to scrutinize business corporations’ social/environmental footprint. The following video explains these trends in more detail.

Video: “[7 Key Business Trends for 2023](#)” by [Shifft](#) [21:52] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

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1.7 CHAPTER SUMMARY & REVIEW



Summary

The first chapter of the Operations Management text outlines the fundamental concepts and significance of operations management in a business context. It defines operations management as the process of transforming inputs into valuable outputs (goods and services) and highlights its critical role in ensuring efficient resource utilization. The chapter emphasizes the importance of operations management for business students, explaining that understanding these processes is vital for managing and improving the systems that create an organization's products or services. Additionally, it covers the historical phases of operations management, from craft manufacturing to mass production and the modern period, showing how the field has evolved in response to changing market demands and technological advancements.

The chapter also differentiates between producing goods and providing services, noting that while goods are tangible and standardized, services are intangible and often require direct customer interaction. It discusses the transformation processes involved in operations management, categorizing them into manufacturing, service, supply, and transport. Furthermore, the chapter highlights the interconnectedness of operations with other business functions like marketing, finance, and human resources, stressing the importance of operations in achieving organizational success. Lastly, it touches upon recent trends in operations management, such as globalization, supply chain expansion, e-commerce, technology, and sustainability, and examines the impact of the COVID-19 pandemic on business practices, pointing out the challenges and opportunities it has created.

OpenAI. (2024, May 7). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Review Questions

1. Define operations management and describe its core functions within a business. How does operations management contribute to the overall success of an organization?
2. Explain the role of operations management in transforming inputs into outputs. Provide an example of this transformation process in a manufacturing setting and in a service setting.
3. Discuss why it is important for business students to study operations management. What benefits can this knowledge provide in a professional career?
4. Identify and discuss some of the professional organizations involved in operations management. How can these organizations benefit students and professionals in the field?
5. Describe the three phases of operations management history: craft manufacturing, mass production, and the modern period. What are the key characteristics and innovations of each phase?
6. Compare and contrast the production of goods and services. What are the main differences in terms of output, customer interaction, labour content, input variability, quality measurement, productivity measurement, and inventory handling?
7. What is a transformation process in operations management? Give examples of different types of transformation processes and explain how they add value to inputs.

8. Explain the concept of operations functions within an organization. How do operations interact with other functional areas, such as marketing, finance, and human resources?
9. Discuss the importance of efficiency and effectiveness in operations management. How can businesses balance these two aspects to create value for customers? Provide examples.
10. Examine the key trends in operations management, including globalization, supply chain expansion, e-commerce, technology, sustainability, and post-COVID trends. How have these trends impacted the field of operations management?

OpenAI. (2024, May 28). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create ten discussion questions based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

Explore the [Resources for Operations Management Learners and Professionals list in section 1.4](#). Select one 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 networking opportunities 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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1.8 KEY TERMS



Key Terms

- **Effectiveness:** It's about doing the right things. This means making choices and taking actions that benefit the business and, most importantly, add value for the customer.
- **Efficiency:** It's about doing things well but without wasting resources. This means finding ways to streamline tasks and avoid unnecessary steps that cost time or money.
- **Finance** is the lifeblood of the company. They manage the money flow, ensuring there's enough to cover everything from materials and payroll to equipment upgrades.
- **Goods:** Tangible products like vehicles, clothing, cell phones, and shovels.
- **HR** is the foundation of any successful organization. They recruit, hire, and train the talented individuals who make up the operations team.
- **Macro-operation** is an overall transformation that is usually required to produce a good or service
- **Manufacture:** This involves physically creating products, such as automobiles.
- **Marketing** acts as the bridge between customers and operations. They ensure the company creates products or services that fulfill customer needs and desires.
- **Micro-operations** are the more detailed transformations within the macro-operation.
- **Operations** encompasses all activities necessary for delivering an organization's goods or services to customers and clients.
- **Operations management** is the management of the processes that transform

inputs into goods and services that add value for the customer.

- **Service:** Service-oriented processes focus on treating customers or storing products, as seen in hospitals or warehouses.
- **Services:** Intangible offerings such as car repairs, haircuts, and medical treatments.
- **Supply:** This encompasses changes in ownership of goods, often observed in retail settings.
- **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.
- **Transport:** Processes related to the movement of materials or customers, such as taxi services.

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CHAPTER 2: OPERATIONS STRATEGY & COMPETITIVENESS

Chapter Overview

[2.0 Learning Outcomes](#)

[2.1 Modern Environment of Business](#)

[2.2 Competitiveness](#)

[2.3 Strategy](#)

[2.4 The Power of Productivity Measurement: Gauging Operational Performance](#)

[2.5 Chapter Summary & Review](#)

[2.6 Chapter Problems](#)

[2.7 Key Terms](#)

2.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Explore the modern environment of business and the key players that can influence business decisions.
- Explain the factors that influence purchasing decisions.
- Differentiate between essential criteria for being considered as a supplier (order qualifiers) and criteria that give a competitive edge (order winners).
- Identify the four main priorities (cost, quality, speed, and flexibility) and the strategies firms use to achieve them.
- Describe the concept of core competency, which refers to a company's unique strengths and capabilities.
- Explain the three levels of strategy—corporate, business, and functional.
- Describe the six categories of operations strategy, such as cost, quality, and innovation.

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2.1 MODERN ENVIRONMENT OF BUSINESS



[“Entrance of Dr. Oetker Canada plant in London, Ontario”](#), [Global Affairs Canada](#), [Crown NC \(CAN\)](#). The Government of Canada is not affiliated with nor endorses the reproduction of its official documents here.

To better appreciate competitiveness, let’s take a look at the dynamic environment of business today and the key players that can impact business decision-making. Consider a business unit like Dr. Oetker’s pizza factory in London, Ontario. That plant is embedded in multiple layers of the environment (local, provincial, national, and international), and its products are prepared there. Within these layers of environment, there are countless players that directly or indirectly can impact what happens inside this factory, as shown in Figure 2.1.1.

These players include ISO, financial institutions, environmental activists, food research institutions, farming, engineering, logistic and IT firms. In addition, four prominent players (suppliers, competitors, customers and regulatory bodies) are present. All these players can interact with each other and collectively influence the decisions made by this company and the activities that take place inside this factory.

For Dr. Oetker, customers are most important because they can determine the sales volume and, hence, the firm's profit. The challenge is what Dr. Oetker should do to win more customers while the competition pursues the same objective. Both are competing for a bigger share of the market, for which they would need suppliers, and both must follow the regulatory standards as they are operating in the food industry. Therefore, their internal decisions and activities (operations) are influenced by external forces, namely, suppliers, customers, and competition. All business firms seek and plan for more profit by expanding their market share. However, the success of such a plan (Strategy) depends on their awareness of the influences in the business environment and their competitiveness.

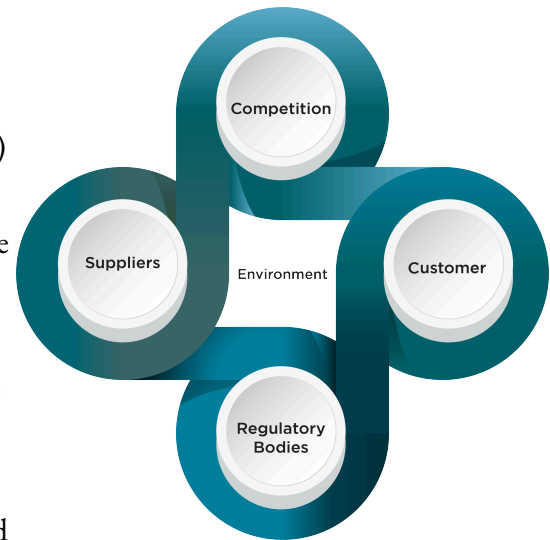


Figure 2.1.1. “Environment Layers” by Sanaz Habibi, [CC BY-NC-SA 4.0](#)

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2.2 COMPETITIVENESS

Competitiveness refers to a firm's ability and performance in selling and supplying goods and services within a given market ("Competition (companies)", 2019). It's about how a company can win over customers to become their preferred choice. Competitive Advantage is achieved by offering better value than competitors through lower prices or higher quality. Key purchasing criteria include price, quality, variety, and timeliness. Customer decisions are influenced by these criteria when choosing a service or product.

Competitive Advantage and Key Purchasing Criteria

Competitive Advantage and Key Purchasing Criteria are two sides of the same coin in business. They both deal with why a customer chooses one company over another.

Competitive advantage is what makes a business stand out from its competitors. It's the reason a customer would choose their product or service over another company's offering. This advantage can come in many forms, like:

- *Lower prices*: Some companies can offer a similar product at a cheaper cost due to efficiencies or economies of scale.
- *Higher quality*: Some companies focus on building superior products that last longer or perform better.
- *Better customer service*: Companies that prioritize customer experience can build loyalty through strong support.
- *Unique features*: A groundbreaking product or service can create a competitive advantage if it fills a specific customer need.

Understanding what motivates buyers is crucial for any organization, regardless of who those buyers are. These motivators, known as Key Purchasing Criteria, are the factors that influence buying decisions.

The Customer isn't always a single person. Sometimes, it can be another company. For example, imagine the City of Toronto buying heavy-duty trucks for park maintenance or Toyota searching for a new supplier of car windshields. In both cases, key purchasing criteria will guide their choices.

Key Purchasing Criteria are the factors that influence a customer's buying decision. When customers consider different options, they will weigh these criteria to determine the best fit for their needs. Here are some common factors:

- *Price*: Firms must understand how much the Customer will pay for an item. If products are seen to be very similar, the Customer will choose based on price.
- *Quality*: Many customers are willing to spend more 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*: A part of the market values 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 to gain new customers. This can also be related to the capability of the company to deliver at the time that they had promised.

By understanding their competitive advantage, a business can tailor their marketing and sales to resonate with a customer's key purchasing criteria. This increases the chance of the Customer choosing them over the competition.

Key Purchasing Criteria

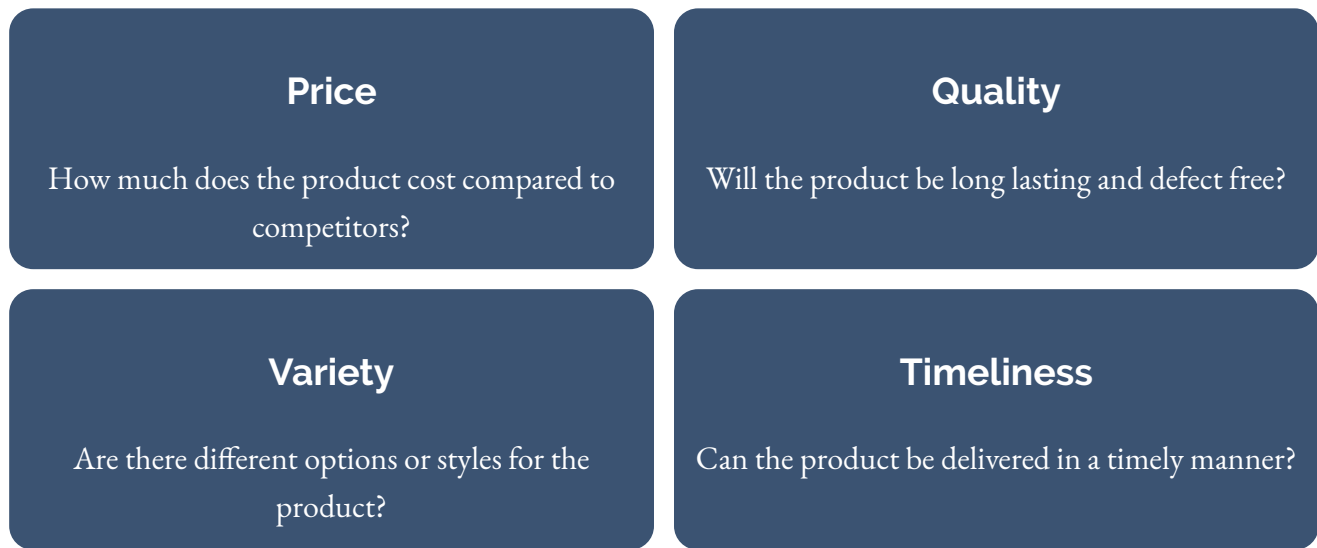


Figure 2.2.1: Categories of key purchasing criteria.

Order Qualifiers vs. Order Winners

Two essential concepts related to purchasing criteria are order qualifiers and order winners, which were initially introduced by Terry Hill (Hill, 2000). When making significant purchases, customers evaluate which characteristics are non-negotiable requirements and which can influence their decision.

Order Qualifiers

These are the non-negotiable features or requirements that customers expect. If a product or service lacks these characteristics, customers will seek alternatives.

For example, minimum safety features and air conditioning might be order qualifiers for a car. In Smartphones, customers expect a minimum level of battery performance, a certain level of display quality is essential, and the phone must function reliably.

Order Winners

These characteristics differentiate a product or service and lead to winning the Customer's order.

Order winners can include new technical features, attractive warranties, service agreements, or competitive pricing.

Over time, what was once an order winner may become an order qualifier and vice versa. For instance, air conditioning in cars was a novelty (order winner) in 1989 but has now become an expected feature (order qualifier). Regarding the example of Smartphones, a superior camera with advanced features can be a decisive

factor; a visually appealing and distinctive design can attract customers, and innovative software functionalities set a product apart.

Marketing teams must understand their customers' order qualifiers and order winners. Operations should promptly address these requirements to meet customer expectations.

These concepts evolve, so businesses must stay attuned to changing customer preferences.

Competitive Priorities

In the world of business, every company wants to be the champion. But how do they win? Operations Management plays a critical role by focusing on four key areas that customers care about: cost, quality, flexibility, and speed.

Cost: Keeping it Affordable

Imagine customers who only want the best deals. For these price-conscious shoppers, companies need to be cost champions. This means finding ways to cut waste and get the most out of everything they have. They become ninjas at identifying and eliminating unnecessary steps in their operations. Reducing mistakes (defects) also saves money, so these companies keep a close eye on quality to keep costs down. Think of it like this: the less you waste, the less you spend!

Quality: Products Worth Bragging About

Some customers value quality above all else. For them, companies strive to be quality kings and queens. This means creating top-notch products and figuring out the best way to make them. Imagine the marketing and engineering teams working together to design amazing products that meet Customer needs precisely. Then, the manufacturing team ensures these products are built perfectly every single time. It's like a two-part recipe for success: a great design and a perfect production process, both working together to satisfy happy customers.

Flexibility: Adapting on the Fly

What if customers want lots of choices and new products all the time? In that case, companies need to be flexibility fighters. They achieve this by using equipment that can handle many different tasks, like a Swiss Army knife of the business world! They also keep some extra space and resources on hand to ramp things up quickly. Imagine having employees who can wear many hats and switch between tasks or machines easily. This allows these companies to get new products to market fast and switch between making different products in a flash. They also want to be able to adjust their production levels quickly if demand changes. Think of it like this: the more adaptable you are, the easier it is to keep up with customer needs.

Delivery: Getting There Fast

Sometimes, speed is king (or queen!). Companies whose customers value fast delivery need to be in the delivery dash. Imagine companies like McDonald's or Amazon – they're all about getting things to you quickly and efficiently. This means having streamlined processes and being super fast at providing their products and services.

By understanding these competitive priorities, operations managers can make strategic decisions to give their company the edge and become the ultimate champion in the eyes of their customers!

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

Trade-offs in Operations: The Balancing Act

Have you ever tried juggling? It takes practice to keep all the balls in the air! In operations management, it's similar. There are many important things to focus on, but you can't necessarily be the best at everything all the time. This is because of trade-offs. Imagine a company that wants to be the absolute cheapest (cost champion). To make fewer mistakes (defects), they might switch to a higher-quality part. But guess what? That usually costs more! This is a classic trade-off between cost and quality.

Just like juggling different coloured balls, there are trade-offs between flexibility and speed. If a company wants to offer many choices (flexibility), it can get complicated to make everything quickly (speed). Think about a pizza place that makes everything from hand-tossed dough to gourmet toppings. It might take longer to get your pie compared to a place with just a few basic options.

Every decision in operations management involves a balancing act. By understanding these trade-offs, companies can determine what matters most to their customers and focus on excelling in those areas.

Core Competencies

Imagine a bakery famous for its mouthwatering pies. What makes their pies so good? Maybe it's a secret family recipe, perhaps it's their generation of baking experience, or maybe it's their special touch for creating flaky crusts. This special something is like a company's core competency.

Core competency is a business term that means a company's unique strengths and talents. It's what makes them stand out from the crowd, just like the secret ingredient that makes those pies so delicious.

This idea of core competencies came from a Harvard Business Review article, ‘The Core Competence of the Corporation,’ written in the 1990s.

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 to succeed against the competition.

Many things can contribute to a company’s core competency. It could be their amazing employees, equipment, a secret formula they hold (like a patent), or even their awesome brand reputation.

The key thing is that a successful company knows what it does better than anyone else and why. Their core competency is the “why” behind their success. By identifying and using their core competency, a company can become the bakery everyone raves about or whatever industry they’re in!

The Core Competency Checklist: Three Must-Haves

In an article, C.K. Prahalad and Gary Hamel came up with a special checklist to identify core competencies.

1. A core competency should deliver a superior value or benefit to the Customer. Think about McDonald’s fries. They might not be the most gourmet, but they’re tasty, consistent, and affordable – a win for customers who want a quick and reliable fry fix.
2. It should be difficult for competitors to imitate. Imagine Apple’s stylish designs. Sure, other companies can make phones, but Apple’s unique design and user experience blend is tough to replicate.
3. A core competency should be rare. Only some companies can have the same strength. Take Walmart’s buying power. Their massive size allows them to negotiate incredible deals with suppliers, giving them a big advantage over smaller competitors. (Twin, 2023).

These three conditions are like a secret code for identifying a company’s strengths. If a strength checks all these boxes, then it’s a core competency. By focusing on these core competencies, businesses can become the McDonald’s of fries, the Apple of style, or the Walmart of low prices, dominating their competition!

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2.3 STRATEGY

The term “strategy” originates from the Greek word “strategos,” which translates to “general.” This etymology reflects the concept’s roots in military tactics, where a strategist guided the overall course of warfare. In the business domain, this notion of leading military campaigns has been adapted to the leadership of business activities. Business strategy entails establishing long-term goals and outlining a course of action for a firm, differentiating it from the day-to-day operational activities.

Operations Strategy and Operations

As previously mentioned, winning a greater market share requires a plan (strategy). Once this plan is set, it should be executed by internal activities (operations) and resources that deliver the plan for the external market. The effectiveness of a plan lies in a realistic grasp of what the customers want, which often tends to be dynamically changing, ambiguous or heterogeneous. On the other hand, internal activities and resources could be complex enough not to change dynamically. Despite this disagreement, the two sides should complement each other. The following video explains this in more detail:

Video: “[The Difference Between Operations and Strategy](#)” by [cmoeinc](#) [5:18] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Organizations and Internal View of Operations Strategy

While the operations strategy is formulated in response to external market demands, the decision-making process and execution occur entirely within the organization. Two prominent approaches to operations strategy exist: top-down and bottom-up. These approaches differ in the organizational levels involved in strategic decision-making. This section will first delve into these two perspectives and then examine the role of organizational hierarchy in formulating strategic choices.

Video: “[Operations Strategy Part 1](#)” by [Dr Ogunseyin](#) [6:20] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

The Strategic Hierarchy: A Framework for Decision-Making

Organizations operate at various levels, each requiring its own strategic focus. Understanding this strategic hierarchy is crucial for effective decision-making.

- At the highest level sits the **corporate strategy**. This broader scope vision defines the company’s core values, mission, and desired competitive advantage. It essentially answers the question: “In which industries should we compete, and how will this create synergy and value for the entire corporation?”
- Next comes the **business-level strategy**. Here, the focus narrows to individual business units (SBUs) within a diversified corporation. This strategy determines how each SBU will achieve a sustainable competitive advantage. Michael Porter’s framework proposes three main approaches: cost leadership (offering the lowest price), differentiation (standing out through unique features), or focus (targeting a specific market niche).
- Delving deeper, we encounter **functional strategies**. These are department-specific plans that support the overall business-level strategy. The marketing department might craft a strategy for brand awareness, while finance might prioritize cost-reduction measures. These functional strategies may have departmental focus, alignment with the business strategy, and focus on short-to-midterm goals.
- Traditional functional structures are sometimes deemed inefficient. In such cases, companies may adopt a structure based on processes or SBUs. An **SBU** is a semi-autonomous unit responsible for its own budgeting, product development, hiring, and pricing decisions. It operates as an internal profit center within the corporation.
- Finally, we reach the **operational strategy**. This highly focused level deals with day-to-day operational activities, such as scheduling production runs or setting quality control parameters. Operational strategies are naturally informed by the business-level strategies, which themselves align with the broader corporate vision.

The strategic hierarchy acts as a framework for decision-making at all organizational levels. Corporate Strategy sets the overall direction, informing business-level strategies, which in turn guide functional and operational activities. This coordinated approach ensures efficient resource allocation and propels the organization toward long-term goals.

Critical Decisions in Operations Strategy: Executing the Game Plan

Operations strategy translates the high-level business strategy into actionable steps. The decisions made at this level determine the success or failure of the overall plan. Here are 10 critical areas that demand careful consideration in operations management (Kettinger Global, 2016):

1. *Product and Service Design:* The fundamental design of your offering significantly impacts production costs and achievable quality. Every aspect, from materials to functionality, plays a role.
2. *Quality Management:* Ensuring your product or service consistently meets specifications is paramount. This may involve implementing methodologies like Statistical Process Control (SPC), Total Quality Management (TQM), or Six Sigma.
3. *Process and Capacity Design:* The type of product, its volume, and variety all influence the optimal production process. For instance, high-volume, standardized products might benefit from assembly lines, while low-volume, customized products might require a more flexible job-shop approach.
4. *Location Strategy:* Decisions regarding the number and placement of facilities are crucial. Factors like proximity to raw materials, transportation networks, and customer base all need to be considered. Location directly impacts the speed of production and customer deliveries.
5. *Layout Design:* This involves strategically positioning workstations, materials handling systems, and information flow within the production facility. Optimizing layout minimizes waste and maximizes efficiency.
6. *Human Resources and Job Design:* Training, motivation, and skill development of your workforce are critical for operational excellence. Job design should balance employee satisfaction with task efficiency.
7. *Supply Chain Management:* Decisions regarding supplier locations and the level of collaboration directly impact cost and delivery speed. Building strong relationships with reliable suppliers is key.
8. *Inventory Management:* Developing strategies for efficient inventory control throughout the supply

chain is essential. This involves balancing the need to have enough materials on hand with the cost of holding excess inventory.

9. *Scheduling*: Effective scheduling of production processes, resources, and employees ensures timely deliveries and customer satisfaction. This requires balancing workload with available resources and capacity.
10. *Maintenance*: Regularly maintaining equipment and machinery minimizes downtime, maintains quality, and ensures smooth and stable production processes.

By carefully considering these 10 critical decisions, organizations can translate their business strategy into a successful operational reality.

Common Operations Strategies: Competing on Quality and Speed

Within the realm of operations strategy, two dominant approaches emerge: quality-based strategies and time-based strategies. Let's explore how these strategies can empower organizations to achieve a competitive edge.

Quality-Based Strategies: Building a Reputation for Excellence

Quality-based strategies are a powerful tool for companies seeking to elevate their market standing. These strategies prioritize continuous improvement in product design and a relentless pursuit of error reduction. By implementing such initiatives, firms establish a reputation for superior quality, fostering customer loyalty and potentially commanding premium pricing.

Several frameworks and methodologies underpin quality-based strategies. Some of the most prominent include:

- **ISO 9001**: This internationally recognized standard provides a framework for establishing a quality management system, ensuring consistent product quality and adherence to customer specifications.
- **Six Sigma**: This data-driven methodology focuses on identifying and eliminating defects in manufacturing and business processes, leading to significant improvements in quality and efficiency.
- **Total Quality Management (TQM)**: A holistic approach to quality management, TQM emphasizes continuous improvement across all organizational levels, fostering a culture of quality that permeates every aspect of the business.

By embracing these quality-focused approaches, companies can enhance customer satisfaction and reduce production costs through minimized rework and improved process efficiency.

Time-Based Strategies: The Race Against the Clock

In today's fast-paced markets, speed can be a significant competitive differentiator. **Time-based strategies** focus on reducing lead time, the time elapsed between a customer's order and product delivery. Companies that can deliver faster often enjoy several advantages:

- *Increased Customer Satisfaction:* Faster deliveries enhance customer experience and satisfaction, potentially leading to repeat business and positive word-of-mouth marketing.
- *Reduced Inventory Costs:* By streamlining processes and minimizing lead times, companies can hold less inventory, reducing associated storage and financing costs.
- *Enhanced Responsiveness to Market Shifts:* Shorter lead times allow organizations to rapidly adapt to changing market demands, potentially introducing new products or modifying existing ones with greater agility.

Lean Production is a prominent methodology frequently employed in time-based strategies. Lean principles focus on eliminating waste in all its forms, from unnecessary production steps to excessive inventory levels. By streamlining processes and optimizing resource allocation, lean production helps companies achieve faster lead times and greater operational efficiency.

The choice between a quality-based or time-based strategy is not always clear-cut. Many organizations incorporate elements of both approaches to achieve a balance between delivering high-quality products and services while maintaining responsiveness to customer needs.

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2.4 THE POWER OF PRODUCTIVITY MEASUREMENT: GAUGING OPERATIONAL PERFORMANCE

In the realm of operations, measurement reigns supreme. A key metric for judging operational effectiveness is productivity. But what exactly is productivity, and how can it be measured?

Understanding Productivity:

- **Relative Measure:** Productivity is a relative measure, meaning it holds little meaning in isolation. Its true value is revealed when compared to a previous period, a similar department, or a competitor. The focus lies on whether productivity has improved, declined, or stagnated.

Types of Productivity Measures

The measure of a firm's **output** depends on the nature of its products. For homogeneous goods, output can be expressed as the number of units produced. However, when dealing with diverse products that vary in labour and material costs, the output is often described in terms of the dollar value of all goods produced within a specific time frame.

Inputs, on the other hand, are typically measured in dollars spent, although exceptions exist (such as labour hours, water usage, or electricity consumption). Productivity is usually assessed for significant expenditures, with farmers, for instance, measuring meat output and feed consumption.

To gain a comprehensive understanding of operational efficiency, we can explore various types of productivity measures:

- **Labour Productivity:** This metric measures the output (goods or services produced) per unit of labour input (typically labour hours).
- **Machine Productivity:** This metric focuses on the output produced per unit of machine time (e.g.,

number of widgets produced per hour of machine operation).

- **Material Productivity:** This metric measures the output per unit of material input (e.g., number of finished products per unit of raw material).
- **Multifactor Productivity:** This broader measure takes into account all inputs (labour, materials, machinery, etc.) to determine the overall efficiency of the production process.

Material Productivity

- Units of output per dollar spent on materials
- Dollars of output per dollar spent on materials
- Dollars of output per unit of material input

Machine Productivity

- Output per machine
- Units of output per machine hour
- Output per machine centre

Labour Productivity

- Dollars of output per labour hour
- Units of output per labour dollar
- Units of output per shift

Energy Productivity

- Units of output per gallon of water
- Dollars of output per dollar of hydro
- Dollars of output per kilowatt hour

Figure 2.3.1: Examples of productivity measures.

Calculating Percent Change

Once you've chosen the appropriate productivity measure, you can calculate the percent change over a specific period. Here's the formula:

$$\text{Percent Change in Productivity} = ((\text{New Period Productivity} - \text{Old Period Productivity}) \div \text{Old Period Productivity}) \times 100$$

Percent Change

$$\text{Percent Change} = \frac{\text{New Value} - \text{Old Value}}{\text{Old Value}} \times 100\%$$

If the result is positive, it is an increase.

If the result is negative, it is a decrease.



Examples of Productivity Measures

Partial Productivity

$$PP = \frac{\text{Output}}{\text{Labour}}$$

$$PP = \frac{\text{Output}}{\text{Energy}}$$

$$PP = \frac{\text{Output}}{\text{Materials}}$$

Multi-factor Productivity

$$MFP = \frac{\text{Output}}{\text{Labour} + \text{Materials}}$$

$$MFP = \frac{\text{Output}}{\text{Energy} + \text{Labour} + \text{Materials}}$$

Total Productivity

$$TP = \frac{\text{Output}}{\text{All inputs}}$$



Example

Let's say a company's labour productivity in the previous quarter was 10 units per labour hour. In the current quarter, the productivity has increased to 12 units per labour hour.

Using the formula, the percent change in productivity is:

$$\text{Percent Change} = ((12 \text{ units/hour} - 10 \text{ units/hour}) \div 10 \text{ units/hour}) \times 100 = 20\%$$

This indicates a 20% improvement in labour productivity over the quarter.

By employing various productivity measures and tracking their changes over time, organizations can gain valuable insights into their operational effectiveness. This allows them to identify areas for improvement, optimize resource allocation, and ultimately achieve a competitive advantage.

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2.5 CHAPTER SUMMARY & REVIEW



Summary

This chapter explores the modern business environment and its impact on competitiveness. A discussion on how businesses like Dr. Oetker's pizza factory must navigate multiple layers of local to international influences, including regulatory bodies, suppliers, customers, and competitors, is included. Competitiveness is defined by a firm's ability to offer better value than competitors, often achieved through lower prices or higher quality. Key purchasing criteria such as price, quality, variety, and timeliness are crucial in customer decision-making. Order qualifiers (non-negotiable features) and order winners (differentiating features) are essential for businesses to understand and leverage to attract customers.

The chapter also delves into competitive priorities—cost, quality, flexibility, and speed—each representing a strategic focus area for operations management. Businesses must navigate trade-offs between these priorities, as excelling in one area often means compromising in another. Core competencies, unique strengths and capabilities are critical for sustaining competitive advantage and must meet specific criteria, including delivering superior value, being difficult to imitate, and being rare. The chapter further outlines the strategic hierarchy from corporate to operational levels, emphasizing the importance of aligning strategies across these levels to achieve overall business goals. Lastly, the chapter addresses critical decisions in operations strategy, such as product design, quality management, and supply chain management, highlighting the necessity of careful planning and execution to maintain competitiveness.

OpenAI. (2024, May 24). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Exercises

1. How do external factors such as regulatory bodies, suppliers, and customers influence a business's internal operations and strategic decisions? Can you provide examples from the chapter?
 2. Discuss the difference between order qualifiers and order winners. How can a company effectively identify and leverage these concepts to gain a competitive advantage in the market?
 3. Explain the four competitive priorities—cost, quality, flexibility, and speed. How do businesses balance these priorities, and what are the potential trade-offs involved?
 4. What are core competencies, and why are they important for a company's long-term success? Discuss the criteria that a core competency must meet according to the chapter.
 5. Describe the strategic hierarchy from corporate strategy to operational strategy. How does alignment across these levels contribute to a company's overall competitiveness and operational efficiency?
 6. What are the ten critical decisions in operations strategy mentioned in the chapter? How do these decisions impact a company's ability to execute its business strategy effectively?
-

OpenAI. (2024, May 28). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create six discussion questions based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

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2.6 CHAPTER PROBLEMS



Problem #1

Billco Windows and Doors is preparing its monthly productivity report. Their monthly costs are shown below. Calculate the:

- a)** Labour productivity (output $\div$ labour hours)
- b)** Machine productivity (output $\div$ machine hours)
- c)** The multifactor productivity (output $\div$ (labour cost + material cost + energy cost)) of dollars spent on labour, materials, and energy. The 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 $\div$ labour hours)

$$= 1800 \div 1975$$

$$= 0.91 \text{ units per labour hour}$$

b) Machine productivity (output $\div$ machine hours)

$$= 1800 \div 425$$

$$= 4.23 \text{ units per machine hour}$$

c) Multifactor productivity (output $\div$ (labour cost + material cost + energy cost))

$$= 1800 \div ((1975 \times \$18) + \$81000 + \$21600)$$
$$= 0.013 \text{ units per dollar spent}$$



Problem #2

A company makes seasonal jams and jellies. Yesterday they produced 520 jars of jam with five workers who each worked an 8-hour day. What was the labour productivity?

Solution

$$= 520 \div 5 \text{ workers} \times 8 \text{ hours}$$
$$= 13 \text{ jars per worker hour}$$



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

$$= 3500 \div (\$1200 + \$90 + \$450)$$
$$= 2.01 \text{ cards per dollar of input}$$



Problem #4

Joe has purchased a pizza franchise and is learning how to measure productivity. Calculate the:

- a) Food cost productivity
- b) Labour productivity
- c) Total productivity

Also, calculate the percent change for each measure.

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

Solution

Question	June	July	% Change
a) Food cost productivity	$52500 \div 15750$ = \$3.33	$59650 \div 16702$ = \$3.57	$(3.57 - 3.33) \div 3.33$ $\times 100$ = +7.02%
b) Labour productivity	$52500 \div 11550$ = \$4.55	$59650 \div 14512$ = \$4.11	$(4.11 - 4.55) \div 4.55$ $\times 100$ = -9.7%
c) Total productivity	$52500 \div (15750 + 11550 + 3500)$ = \$1.70	$59650 \div (16702 + 14512 + 3500)$ = \$1.72	$(1.72 - 1.70) \div 1.70$ $\times 100$ = +1.2%

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2.7 KEY TERMS



Key Terms

- **Business Strategy** entails establishing long-term goals and outlining a course of action for a firm, differentiating it from the day-to-day operational activities.
- **Business-level Strategy** Here, the focus narrows to individual business units (SBUs) within a diversified corporation.
- **Competitive Advantage** is what makes a business stand out from its competitors.
- **Competitiveness** refers to a firm's ability and performance in selling and supplying goods and services within a given market ("Competition (companies)", 2019).
- **Core Competencies** are the resources and capabilities that comprise the strategic advantages of a business.
- **Corporate Strategy** is a broader scope vision that defines the company's core values, mission, and desired competitive advantage.
- **Functional Strategies** are department-specific plans that support the overall business-level strategy.
- **Inputs** are typically measured in dollars spent, although exceptions exist (such as labour hours, water usage, or electricity consumption).
- **ISO 9001**: This internationally recognized standard provides a framework for establishing a quality management system, ensuring consistent product quality and adherence to customer specifications.
- **Key Purchasing Criteria** are the factors that influence a customer's buying decision. These include price, quality, variety, and timeliness.

- **Labour Productivity:** This metric measures the output (goods or services produced) per unit of labour input (typically labour hours).
- **Lean Production** is a prominent methodology frequently employed in time-based strategies. Lean principles focus on eliminating waste in all its forms, from unnecessary production steps to excessive inventory levels.
- **Machine Productivity:** This metric focuses on the output produced per unit of machine time (e.g., number of widgets produced per hour of machine operation).
- **Material Productivity:** This metric measures the output per unit of material input (e.g., number of finished products per unit of raw material).
- **Multifactor Productivity:** This broader measure takes into account all inputs (labour, materials, machinery, etc.) to determine the overall efficiency of the production process.
- **Operational Strategy:** This highly focused level deals with day-to-day operational activities, such as scheduling production runs or setting quality control parameters.
- **Output:** For homogenous goods, output can be expressed as the number of units produced. However, when dealing with diverse products that vary in labour and material costs, the output is often described in terms of the dollar value of all goods produced within a specific time frame.
- **Quality-based Strategies** prioritize continuous improvement in product design and a relentless pursuit of error reduction.
- **Six Sigma:** This data-driven methodology focuses on identifying and eliminating defects in manufacturing and business processes, leading to significant improvements in quality and efficiency.
- **Strategic Business Unit (SBU)** is a semi-autonomous unit responsible for its own budgeting, product development, hiring, and pricing decisions. It operates as an internal profit center within the corporation.
- **Time-based Strategies** focus on reducing lead time, the time elapsed between a customer's order and product delivery.
- **Total Quality Management (TQM):** A holistic approach to quality management, TQM emphasizes continuous improvement across all organizational levels, fostering a culture of quality that permeates every aspect of the business.

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CHAPTER 3: FORECASTING

Chapter Overview

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3.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Define forecasting and differentiate it from related concepts such as prediction.
- Describe the role of forecasting in marketing strategy implementation.
- Outline the differences between qualitative and quantitative forecasting methods.
- Perform forecast calculations such as simple moving averages, weighted moving averages, and exponential smoothing.
- Use associative/causal methods of forecasting for operational decision-making.
- Calculate forecasts using time series analysis and seasonal index.
- Calculate Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE) to assess forecast accuracy.

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3.1 GOING WITH THE FLOW FOR BUSINESS SUCCESS

In the previous chapter, we learned about the players in multiple layers of the modern business environment and identified customers, competitors, suppliers, and government as the four key players. These and many other players can be influenced by the economic, technological, and social forces, which can change the climate in the marketplace.

For a profit-seeking firm, the most prominent player is the customer. However, with climate change, the marketplace's requirements dynamically change, and customers become heterogeneous in what they want and ambiguous in the sense that sometimes they need to learn what they want and why. The inevitable result is a market that might be different in the future than it is now. To remain competitive, a business firm should adapt to these changes, go with the flow, and foresee how things might change. To do so, business firms use forecasting. The following video explains what forecasting is in simple terms.

Video: “[What is Forecasting?](#)” by [Marketing Business Network](#) [2:13] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

The following video explains forecasting and why and how it is done.

Video: “[What is Forecasting? | Process & Benefits of Forecasting](#)” by [Educationleaves](#) [5:04] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

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3.2 THE ROLE OF FORECASTING IN MARKETING STRATEGY

This chapter delves into forecasting, a crucial component of marketing strategy implementation. **Forecasting** is the process of predicting future events or trends by analyzing historical and contemporary data. It is most commonly achieved through trend analysis, aiming to estimate a variable of interest at a specified future time. While similar, prediction is a broader term encompassing various methodologies.

Within marketing, forecasting practices encompass formal statistical methods employing time series, cross-sectional, or longitudinal data. Additionally, less formal judgmental methods may be used. It's noteworthy that the terminology can differ across disciplines. For instance, "forecast" is reserved for specific future time point estimations in hydrology. At the same time, "prediction" refers to more general conjectures, such as the number of times floods will occur over a long period.

Uncertainty and Risk in Forecasting

Uncertainty and risk are inherent aspects of forecasting and prediction. Best practices dictate that the extent of uncertainty associated with a specific forecast should be explicitly communicated. Data accuracy is paramount for generating reliable forecasts. In some instances, the data employed for predicting the variable of interest is itself a forecast (Forecasting, 2020).

Sales Forecasting and Strategic Alignment

Marketing strategies must be aligned with the overarching corporate strategy. Sales forecasting, which entails estimating a company's future sales volume, plays a vital role in this strategic synchronization. When implementing a marketing strategy, the entire organization must be prepared to address its ramifications. A critical aspect of this execution is the sales forecast. This Forecast is a benchmark for production, inventory management, and resource allocation across the organization.

The Consequences of Inaccurate Forecasts

Accuracy is paramount in sales forecasting. Overestimation of product demand can lead to excessive expenditures on manufacturing, distribution, and customer service activities that ultimately go unused. Conversely, underestimating demand can be equally detrimental. When a new product is launched,

marketing and sales initiatives are implemented to generate demand. However, if the company is unable to fulfill the market's requirements, competitors can capitalize by capturing those sales.

A company needs to conduct accurate demand forecasting to maintain its competitive position in the market. The following video explains demand forecasting and how it should be done.

Video: “[What is Sales forecasting?](#)” by [Educationleaves](#) [8:34] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Elements of a Sales Forecast

A sales forecast encompasses more than just the company's anticipated sales figures. The process is multifaceted, as the company's sales potential depends on various factors such as pricing strategy and competitor actions. Each of these variables needs to be factored into the sales forecast to determine a realistic sales projection. As these elements change, the Forecast must be revised to maintain accuracy. Consequently, a sales forecast is a dynamic composite of numerous constantly evolving estimates.

Market Potential and Sales Potential

A typical initial step involves determining market potential, which refers to the total projected industry-wide sales for a particular product category within a given timeframe. Market research firms like Nielsen and Gartner estimate market potential for various products and offer this data to companies within those industries.

Once market potential is established, the company's sales potential can be estimated. This represents the maximum anticipated revenue or unit sales achievable for the product. Sales potential is typically expressed as a percentage of the market potential, reflecting the company's projected maximum market share for the designated timeframe. By incorporating sales forecasts into budgets, companies can effectively compare projected revenue against market potential and product costs.

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3.3 FORECASTING HORIZONS AND THEIR APPLICATIONS

The selection of an appropriate forecasting horizon is crucial for effective decision-making within an organization. Forecasting horizons can be broadly categorized into three distinct temporal scopes: long-term, medium-term, and short-term.

Long-Term Forecasting (LT)

Long-term forecasting, typically encompassing a timeframe exceeding two years, is often undertaken at the strategic level of an organization. Due to the inherent high degree of uncertainty associated with such extended timeframes, this approach necessitates a deep understanding of the target products and markets. Long-term forecasts are particularly relevant for strategic decisions concerning new product launches, implementing emerging technologies, and establishing new facilities. Notably, the absence of historical data often presents a significant challenge in long-term forecasting, requiring a greater reliance on expert judgment and scenario planning techniques.

Medium-Term Forecasting (MT)

Medium-term forecasting, also referred to as intermediate-term forecasting, typically spans from several months to two years into the future. This timeframe allows for the utilization of both quantitative and qualitative forecasting methodologies. Medium-term forecasts are instrumental in tactical decision-making, informing strategic initiatives and operational planning.

Short-Term Forecasting (ST)

Short-term forecasting focuses on a timeframe ranging from daily to a few months. These forecasts are primarily employed for operational decision-making processes, such as inventory management, production scheduling, and workforce allocation. Quantitative methods, particularly time series analysis, are prominently used in short-term forecasting due to their effectiveness in analyzing and extrapolating from historical data.

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3.4 TYPES OF FORECASTS

Organizations typically use three major types of forecasts for planning their future operations:

1. **Economic forecasts.** Economic forecasts address the overall business cycle and predict economic indicators such as housing starts, inflation rates, money supply, and others. These forecasts help organizations anticipate and plan for broader economic conditions impacting their operations.
2. **Technological forecasts.** Technological forecasts monitor the rates of technological progress and trends. These forecasts enable organizations to stay abreast of emerging technologies that could lead to new products, processes, or services. Anticipating technological advancements allows companies to plan for potential new facilities, equipment, or infrastructure needed to capitalize on those technologies.
3. **Demand forecasts** (or sales forecasts). Demand forecasts, also known as sales forecasts, estimate consumers' future demand for a company's products or services. These forecasts drive critical operational planning decisions such as production scheduling, capacity planning, inventory management, financial planning, workforce planning, and marketing strategies (The Art and Science of Forecasting in Operations Management, n.d.).

The sources emphasize that demand/sales forecasts are particularly crucial for operations managers, as they inform decisions related to resource allocation, capacity utilization, supply chain management, and overall operational efficiency to meet the anticipated demand effectively.

While the time horizons may vary (short-term, medium-term, or long-term), these three types of forecasts provide organizations with insights into economic conditions, technological landscapes, and customer demand, enabling them to plan and align their operations accordingly and proactively.

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3.5 CATEGORIES OF FORECASTING METHODS

Qualitative Forecasting

Qualitative forecasting techniques, unlike their quantitative counterparts, rely on subjective judgments and opinions rather than historical data. These methods are particularly valuable when historical data is scarce or inapplicable, such as in situations involving new products, emerging markets, or disruptive technologies. They are typically employed for intermediate-term or long-term forecasts that inform strategic decision-making.

Several established qualitative forecasting techniques exist, each offering unique advantages.

Qualitative Forecasting Methods:

1. Executive Judgement (Top Down)
2. Sales Force Opinions (Bottom-up)
3. Delphi Method
4. Market Surveys

Executive Judgement (Top Down)

This approach leverages the expertise of high-level executives within an organization. These executives collaboratively analyze market data, identify future trends, and potentially utilize statistical models and market research to arrive at a consensus forecast.

Sales Force Opinions (Bottom-up)

The sales force, by virtue of their direct customer interaction, possesses valuable insights into customer behaviour and market trends. This approach solicits individual sales forecasts from sales personnel within

their designated territories. These individual forecasts are then aggregated to form a comprehensive forecast for a district or region.

Delphi Method

Developed by the Rand Corporation, the Delphi Method provides a structured approach to gathering expert opinions. A panel of experts anonymously participates in a series of surveys, iteratively refining their forecasts based on the anonymized collective insights provided. This anonymity fosters open and unbiased consideration of all perspectives, ultimately leading to a consensus forecast.

Market Surveys

Market research firms can be employed to conduct surveys that gauge consumer sentiment toward products and future purchasing intentions. The resulting data provides valuable qualitative insights to inform forecasting models.

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 categorized 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).

Quantitative Forecasting Methods:

1. Associative Models
 1. Linear Regression
 2. Multiple Linear Regression
0. Time Series Models
 1. Naïve
 2. Simple Moving Average
 3. Exponential Smoothing
 4. Trend Projection Model

The quantitative forecasting methods will be explained in detail in the following section.

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3.6 ASSOCIATIVE MODELS/ CAUSAL (ECONOMETRIC) FORECASTING

Associative model forecasting methods, also known as causal or econometric forecasting methods, are quantitative techniques used in operations management to predict future values of a variable by analyzing its relationship with other related variables. These methods are particularly useful when historical data is available for both the variable of interest and the potential causal factors influencing it.

Associative forecasting models, unlike time-series methods, consider multiple independent variables (causal factors) that are related to or influence the forecasted dependent variable. These models aim to establish and quantify the cause-and-effect relationships between the independent and dependent variables, enabling more accurate predictions by accounting for the impact of various factors. These factors, termed explanatory variables, can significantly improve the accuracy of forecasts. For instance, incorporating climate data into a sales forecast model for umbrellas can enhance its predictive power.

Some forecasting methods try to identify the underlying factors that might influence the variable being forecasted. 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.

Regression Analysis

Regression analysis is one of the most widely used associative forecasting methods, which involves constructing a mathematical equation that relates the dependent variable to one or more independent variables. This statistical technique estimates the relationships between variables. It encompasses a diverse set of methods for modelling and analyzing the interplay between a dependent variable (the variable being forecast) and one or more independent variables (factors believed to influence the dependent variable). Regression analysis is particularly valuable for understanding how changes in independent variables impact the average value of the dependent variable while holding all other independent variables constant.

The coefficients of the independent variables in the regression equation represent the magnitude and direction of their impact on the dependent variable.

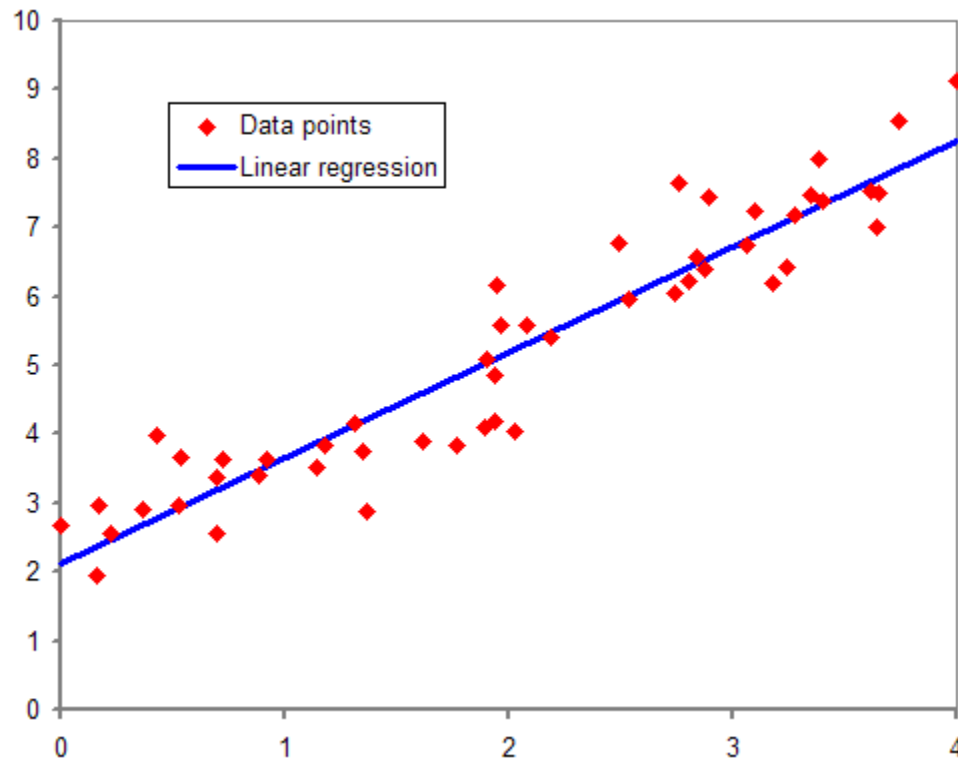


Figure 3.6.1: Example of regression analysis.

Image Description

The image is a scatter plot depicting data points and a linear regression line. The x-axis ranges from 0 to 4. The y-axis ranges from 0 to 10. The red diamonds represent the data points. The blue line represents the linear regression line, showing the best-fit line through the data points.

The data points follow an upward trend, indicating a positive correlation between the variables. The linear regression line slopes upward from left to right, suggesting a strong linear relationship. The legend in the plot identifies the red diamonds as “Data points” and the blue line as “Linear regression.”

Simple Linear Regression

In its simplest form, a linear regression model with a single independent variable can be expressed as:

$$Y = bX + a$$

Where:

‘Y’ is the dependent variable (the variable being forecasted)

‘X’ is the independent variable (the causal factor)

‘b’ is a slope of the regression line (a measure of its steepness, i.e. the ratio of the rise to the run, or rise divided by the run)

‘a’ is Y-intercept (the point on the Y-axis by which the slope of the line sweeps)

Multiple Linear Regression

When there are multiple independent variables influencing the dependent variable, a multiple linear regression model can be employed:

$$Y = a + b^1X^1 + b^2X^2 + \dots + b^{\diamond}X^{\diamond}$$

Where:

- $X^1, X^2, \dots, X^{\diamond}$ are the independent variables (causal factors)
- $b^1, b^2, \dots, b^{\diamond}$ are the regression coefficients associated with each independent variable

Correlation Analysis

Correlation analysis is often used with regression analysis to measure the strength and direction of the linear relationship between the dependent and independent variables. The correlation coefficient, denoted by r , ranges from -1 to 1, with values closer to 1 or -1 indicating a stronger linear relationship and values closer to 0 indicating a weaker or no linear relationship.

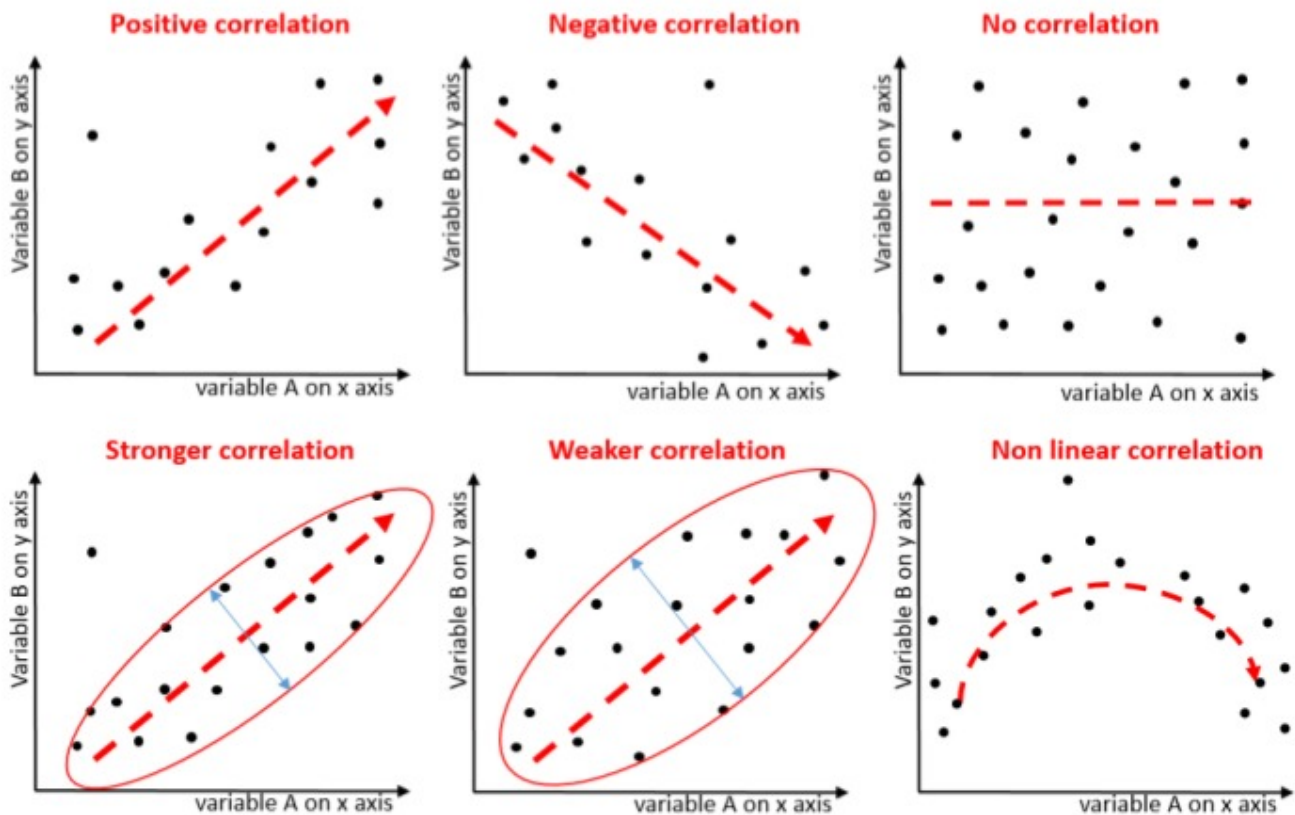


Figure 3.6.2 “Correlation based on direction, form, and dispersion strength” by Sunil Kumar, CC BY 4.0

Figure 3.6.2 consists of six scatter plot diagrams demonstrating correlations between variables A (on the x-axis) and B (on the y-axis).

- *Positive correlation:* A scatter plot with points roughly following an upward-sloping line from the bottom left to the top right. The red dashed line indicates a positive slope.
- *Negative correlation:* A scatter plot with points roughly following a downward-sloping line from the top left to the bottom right. The red dashed line indicates a negative slope.
- *No correlation:* A scatter plot with points scattered randomly with no discernible pattern. The red dashed line is flat, indicating no correlation.
- *Stronger correlation:* A scatter plot where points are tightly clustered around a red dashed upward-sloping line. The points are enclosed within a narrow ellipse.
- *Weaker correlation:* A scatter plot where points are more loosely clustered around a red dashed upward-sloping line. The points are enclosed within a wider ellipse.
- *Non-linear correlation:* A scatter plot where points follow a curved pattern, suggesting a quadratic relationship. The red dashed line forms an upward arch, indicating a non-linear correlation.

Applications in Operations Management

Associative forecasting methods are widely used in operations management for various purposes, including:

1. *Demand forecasting*: Predicting future demand for products or services by considering advertising expenditure, competitor pricing, economic indicators, and demographic variables.
2. *Capacity planning*: Estimating the required production capacity by analyzing the relationships between demand, production rates, and other operational factors.
3. *Inventory management*: Forecasting inventory levels by considering factors such as demand patterns, lead times, and supply chain dynamics.
4. *Resource allocation*: Optimizing the allocation of resources (e.g., workforce, materials, equipment) based on forecasted demand and operational constraints.
5. *Supply chain management*: Predicting supply chain performance metrics (e.g., lead times, costs, service levels) by considering factors such as supplier performance, transportation modes, and logistics networks.

(Frenzel, 2023).

Associative forecasting methods provide a powerful tool for operations managers to make informed decisions by accounting for the complex relationships between various factors and the variables of interest. However, it is crucial to ensure the validity of the underlying assumptions, the quality of the data, and the appropriate selection and evaluation of the forecasting models.



Common Forecasting Assumptions

1. Forecasts are rarely, if ever, perfect. It is nearly impossible to estimate 100% accurately what the future will hold. Firms need to understand and expect some errors 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.

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3.7 TIME SERIES MODELS

Time series data plays a fundamental role in forecasting. A time series collects data points meticulously ordered along a time axis. These data points can be recorded at consistent or irregular intervals. Examples of time series data include ocean tide heights, sunspot counts, and daily closing values of stock market indices. Line charts are a prevalent method for visualizing time series data.

Excel offers a forecast function that can be used for forecasting. The following video shows how it is done.

Video: “[The Excel FORECAST Function](#)” by [Technology for Teachers and Students](#) [5:31] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

The application of time series analysis extends across numerous disciplines, including statistics, signal processing, pattern recognition, econometrics, mathematical finance, weather forecasting, earthquake prediction, and various domains of applied science and engineering that involve temporal measurements. By leveraging time series data, these fields can uncover hidden patterns, trends, and seasonality within the data, enabling the formulation of data-driven forecasts for future outcomes (Singla, 2018).

Selecting the Appropriate Time Interval for Data Collection

A critical aspect of forecasting accuracy lies in determining the optimal time interval for data collection. The chosen interval directly impacts the level of data fluctuation observed. This fluctuation can manifest as trends, seasonal patterns, cyclical variations, or random noise. Understanding the specific fluctuation behaviour of the data is instrumental in selecting the most suitable forecasting technique.

It’s important to remember that time intervals are inherently relative. Terms like “short-term,” “medium-term,” and “long-term” are context-dependent. Table 3.7.1 overviews various forecasting techniques, categorized based on their typical time horizons. Generally, short-term forecasts involve data collected over less than three months, while medium-term forecasts encompass three months to 2 years. Long-term forecasts, however, deal with data collected over a timeframe exceeding two years.

Table 3.7.1 Selecting the Appropriate Time Interval for Data Collection (Singla, 2018)

Time Period	Data Pattern	Forecasting Technique
Short term: less than 3 months	Data does not show any particular pattern or variation	• Simple Moving Average, • Weighted moving average and • Exponential Smoothing
Medium-term: 3 months to two years	Data either repeats periodically or moves in a particular direction, i.e. upward or downward.	• Seasonal and Trend Variation
Long-term: more than 2 years	Data shows a repeated pattern but at irregular intervals with irregular intensity.	• Cyclical method

Time Period Selection and Forecast Accuracy

The chosen time period for data collection plays a crucial role in forecast accuracy. While a longer timeframe may intuitively suggest more reliable results, older data may lose relevance in the present context. Conversely, relying solely on recent data might not provide a sufficient historical foundation for generating dependable forecasts. This highlights the importance of striking a balance between the time period selected and the availability of relevant data within that timeframe. Ultimately, the optimal time horizon depends on the specific forecasting problem and the nature of the data itself.

Trend Analysis

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

- *Trend* – This component represents a consistent upward or downward movement in the data over time. The product life cycle often plays a role in shaping this trend. A new product might exhibit a rising sales trend, while a mature product might show a declining trend.
- *Cyclical* – Cyclical patterns are characterized by recurring fluctuations in the data that typically span more than a year. These cycles can be linked to factors like interest rates, political climates, consumer confidence, or broader market dynamics.
- *Seasonal* – Many products exhibit seasonal patterns, featuring predictable changes in demand that recur annually. Fashion apparel and sporting goods are prime examples of products significantly impacted by seasonality. Demand for winter coats surges during the cold season, while swimwear sales peak during

summer.

- *Irregular variations* – Unforeseen events or series of events can influence demand in unpredictable ways. These irregular variations, often referred to as outliers, are not expected to be repeated in the future. Examples include extreme weather events, labour strikes, or power outages. These events can cause sudden spikes or dips in demand data.
- *Random variations* – Random variations, also referred to as noise, represent the unexplained fluctuations in demand that persist even after accounting for all other identifiable components. These variations are inherent in any time series data and cannot be attributed to any specific cause.

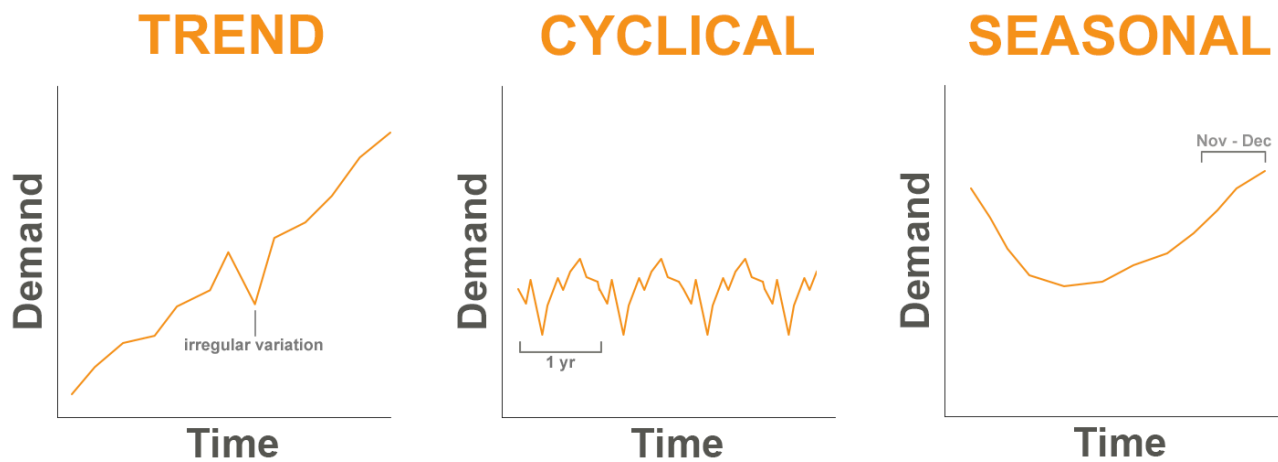


Figure 3.7.1: Diagram of trend, cyclical, and seasonal demand patterns.

Naïve Method

The **naïve approach**, also known as naive forecasting or naïve method, is one of the simplest forecasting techniques used in operations management. It involves using the actual value from the previous period as the forecast for the next period without considering any other factors or patterns in the data.

The naïve approach is based on the assumption that the future value of a variable will be the same as its most recent observed value. Its characteristics include simplicity, no trend or seasonality consideration, and limited data requirements. (What do you need to know about naïve forecasting?, 2024)

Advantages	Disadvantages
Easy to implement	Ignores patterns and trends
It can serve as a baseline or benchmark for comparison	Unsuitable for new products/services
Suitable for stable demand	Reactive rather than proactive

Simple Moving Average

The **simple moving average method** is fundamental for forecasting future values based on historical data. It operates by calculating the average of the data points from the most recent n periods. The selection of the appropriate value for n is crucial and can be influenced by various factors, such as the underlying data characteristics and the desired forecast accuracy. For instance, a manager might leverage demand data from the past four periods ($n = 4$) to generate a 4-period moving average forecast for the upcoming period.

This method is advantageous due to its simplicity and ease of computation. However, it also has limitations. By assigning equal weight to all data points within the window, it may not adequately capture recent trends or sudden shifts in the data. More sophisticated moving average methods address this limitation by incorporating weights that prioritize the most recent data points, placing greater emphasis on their influence on the forecast.



Example

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 = $F_5 = (D_4 + D_3 + D_2) \div 3 = (40 + 34 + 37) \div 3 = 111 \div 3 = 37$

Weighted Moving Average

This method is the same as the simple moving average, with the addition of a weight for each 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

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

Solution

Forecast for period 5 = $F_5 = (0.5 \times D_4 + 0.3 \times D_3 + 0.2 \times D_2) = (0.5 \times 40 + 0.3 \times 34 + 0.2 \times 37) = 37.6$

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

The **exponential smoothing method** integrates the most recent actual demand and the previous forecast to generate the forecast for the upcoming period. This approach offers several advantages. Firstly, it often yields more accurate forecasts. Secondly, it is a straightforward method that enables forecasts to adapt to new trends or changes in demand patterns swiftly. A notable benefit of exponential smoothing is that it does not necessitate a large volume of historical data.

Exponential smoothing employs a smoothing coefficient, denoted as Alpha (α). The value of Alpha determines the rate at which the forecast responds to fluctuations in demand. Consequently, Alpha is also referred to as the Smoothing Factor. A higher value of Alpha implies that the forecast will react more rapidly

to changes in demand, while a lower value will result in a more gradual response, effectively smoothing out the fluctuations.

In essence, the exponential smoothing method balances the most recent demand observation and the previous forecast, with the smoothing coefficient Alpha governing the relative weights assigned to each component. This approach enables the forecast to adapt to evolving demand patterns while mitigating the impact of random fluctuations, thereby enhancing forecast accuracy and responsiveness.

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

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 forecasts for any of the past periods, we would need to initiate this method of forecasting by making some assumptions. This is explained in the next example.



Example

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

In this example, period 5 is the 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 four first. However, a similar issue exists for period four 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 assumptions 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 two 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	$(1 - 0.3) \times 42 + 0.3 \times 42 = 42$
3	34	$(1 - 0.3) \times 42 + 0.3 \times 37 = 40.5$
4	40	$(1 - 0.3) \times 40.5 + 0.3 \times 34 = 38.55$
5		$(1 - 0.3) \times 38.55 + 0.3 \times 40 = 38.985$

Figure 3.7.2:
Solution for
Exponential
Smoothing
Version 1

[Accessible format for Figure 3.7.2](#)

Version #2:

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



Example

Assume you are given an alpha of 0.3

Period	Actual Demand	Forecast
1	60	55 (assumed = α)
2	55	$55 + 0.3 \times (60 - 55) = 56.5$
3	51	$56.5 + 0.3 \times (55 - 56.5) = 56.05$
4	58	$56.05 + 0.3 \times (51 - 56.05) = 54.53$
5		$54.53 + 0.3 \times (58 - 54.53) = 55.64$

Figure 3.7.3:
Solution for
Exponential
Smoothing
Version 2

[Accessible format for Figure 3.7.3](#)

Seasonal Index

A **seasonal index** is a statistical tool used in forecasting to quantify and account for recurring seasonal patterns or demand fluctuations over a specific period.

It helps to identify and measure the impact of seasonal factors (e.g. holidays, weather, etc.) on demand for a product or service so that the organizations adjust forecasts to account for predictable seasonal variations.

The seasonal index is calculated by comparing demand during a specific season/period to the average demand across all seasons/periods. It is typically calculated as a ratio or percentage, with an index value above one indicating higher than average demand and below 1 indicating lower demand.

Historical demand data is deseasonalized by dividing it by the respective seasonal index to remove seasonal effects. Forecasting methods like moving averages or exponential smoothing are applied to the deseasonalized data. The resulting forecast is then re-seasonalized by multiplying it with the appropriate seasonal indexes.

Seasonal indexing is useful for products/services with recurring seasonal demand patterns like holidays, back-to-school, weather changes, etc. It helps to plan inventory levels, staffing, promotions, and other operations aligned with expected seasonal fluctuations (Singla, 2018).



Example

Season	Previous Sales	Average Sales	Seasonal Index
Winter	390	500	$390 \div 500 = .78$
Spring	460	500	$460 \div 500 = .92$
Summer	600	500	$600 \div 500 = 1.2$
Fall	550	500	$550 \div 500 = 1.1$
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's annual demand will be 2500 units.

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

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3.8 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).

Mean Absolute Deviation (MAD)

The **Mean Absolute Deviation (MAD)** measures the average magnitude of the forecast errors without considering their direction (positive or negative). It is calculated as the arithmetic mean of the absolute differences between the forecasted and actual values:

$$MAD = \frac{\sum |\text{Actual Value} - \text{Forecasted Value}|}{n}$$

Where n is the number of observations.

MAD is expressed in the same units as the data, making it easy to interpret and understand. A lower MAD value indicates better forecast accuracy.

To obtain the MAD of the given data, the following steps should be followed:

Step 1: Calculate forecast errors, i.e. find the difference between forecast and actual data.

Step 2: Take an absolute of forecast error, i.e. consider the positive of even those negative forecast error values.

Step 3: Find the average of these absolute values. (Singla, 2018)

Mean Square of Errors (MSE)

The **Mean Squared Error (MSE)** is a measure that squares the forecast errors before averaging them. This squaring process gives more weight to larger errors, making MSE more sensitive to outliers compared to MAD:

$$MSE = \frac{\sum (\text{Actual Value} - \text{Forecasted Value})^2}{n}$$

MSE is expressed in squared units of the data, which can make interpretation more difficult. However, it is a statistically valuable measure as it is used in many advanced forecasting models and optimization techniques.

To obtain the MSE of given data, the following steps should be followed:

Step 1: Calculate forecast errors, i.e. find the difference between forecast and actual data.

Step 2: Take a square of each forecast error value.

Step 3: Find the average of these squared values. (Singla, 2018)

Mean Absolute Percent Error (MAPE)

The **Mean Absolute Percentage Error (MAPE)** is a relative measure that expresses the forecast errors as a percentage of the actual values. It is particularly useful when working with data from different scales or units:

$$MAPE = \frac{\frac{\sum |Actual Value - Forecasted Value|}{Actual Value}}{n} \times 100\%$$

MAPE is expressed as a percentage, making it easy to interpret and compare across different data sets. However, it can be problematic when dealing with actual values close to zero, resulting in extremely high or undefined MAPE values.

To obtain MAPE of given data, the following steps should be followed:

Step 1: Calculate forecast errors, i.e. find the difference between forecast and actual data.

Step 2: Take an absolute of forecast error, i.e. consider the positive of even those negative forecast error values.

Step 3: Divide each absolute value by actual demand value and multiply it by 100 to get data in percentage terms.

Step 4: Find the average of these calculated percentage values. (Singla, 2018)

The computation of methods of forecast error has been illustrated in the following example.



Example

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 $\text{Abs}(e_t)$ refers to the absolute value of the error in period t (e_t).

Period	Actual Demand	Forecast	e_t	$\text{Abs}(e_t)$	e_t^2	$[\text{Abs}(e_t) \div D_t] \times 100\%$
1	63	68				
2	59	65				
3	54	61				
4	65	59				

Here are the steps:

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., $\text{Abs}(e_t)$], 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 $[\text{Abs}(e_t) \div D_t] \times 100\%$ for each period and enter the value under its column in the table above.

Solution

Period	Actual Demand	Forecast	e_t	Abs (e_t)	e_t^2	$[Abs(e_t) \div D_t] \times 100\%$
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%

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3.9 CHAPTER SUMMARY & REVIEW



Summary

The chapter focuses on the essential role of forecasting in business, especially in marketing strategy implementation. Forecasting involves predicting future trends based on historical and current data, employing both formal statistical methods and less formal judgmental approaches. It helps businesses anticipate market changes and adapt accordingly. The chapter emphasizes the importance of accurate forecasting in aligning marketing strategies with corporate goals, particularly through sales forecasting, which guides production, inventory management, and resource allocation. It also discusses the critical nature of accurate forecasts to avoid overestimation or underestimation of product demand, both of which can have significant financial repercussions.

Furthermore, the chapter explores different types of forecasts—economic, technological, and demand—and their applications in operations management. It explains various forecasting horizons (long-term, medium-term, and short-term) and their respective uses. The chapter also delves into qualitative and quantitative forecasting methods, highlighting techniques such as executive judgment, market surveys, regression analysis, and time series analysis. Each method has its unique advantages and is selected based on the availability of data and the specific forecasting requirements. Additionally, it addresses common forecasting assumptions and the importance of selecting appropriate time intervals for data collection to enhance forecast accuracy.

OpenAI. (2024, June 7). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Review Questions

1. What is the importance of forecasting in maintaining a competitive position for a profit-seeking firm, especially in a dynamically changing market environment?
2. Describe the role of forecasting in aligning marketing strategies with corporate strategies. Why is sales forecasting particularly crucial in this alignment?
3. Explain the three main types of forecasts (economic, technological, and demand) discussed in the chapter. How do these forecasts contribute to operational planning within an organization?
4. Discuss the differences between qualitative and quantitative forecasting methods. Provide examples of when each type would be most appropriately used.
5. What are the main challenges associated with long-term forecasting, and how do businesses typically address these challenges?
6. How does the concept of 'market potential' differ from 'sales potential,' and why is it important for companies to understand both when creating sales forecasts?
7. What is the impact of inaccurate sales forecasts on a company's operations and financial performance? Provide examples of both overestimation and underestimation scenarios.
8. Define and compare the three forecasting horizons: short-term, medium-term, and long-term. Give an example of a business decision that would be influenced by each horizon.
9. Discuss the role of regression analysis in associative forecasting methods. How does it help in understanding the relationships between different variables?
10. Explain the significance of forecast accuracy measures such as Mean Absolute

Deviation (MAD), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE). Why is it important to use these measures in evaluating forecasting models?

OpenAI. (2024, June 7). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create ten discussion questions based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

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3.10 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. $(357 + 319 + 360) \div 3 = 345.3$
3. $360 \times .5 + 319 \times .3 + 357 \times .2 = 347.1$
4. $350 + .2(360 - 350) = 352$



Problem #2

Demand for aqua fit classes at a large Community Centre 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	$(162 + 158) \div 2 =$ 160		130
4	190	$(158 + 138) \div 2 =$ 148	$138 \times .6 + 158 \times .3 + 162 \times .1$ = 146.4	$130 + .3 \times (138 - 130) =$ 132.4
5	182	$(138 + 190) \div 2 =$ 164	$190 \times .6 + 138 \times .3 + 158 \times .1$ = 171.2	$132.4 + .3 \times (190 - 132.4)$ = 149.7
6	177	$(190 + 182) \div 2 =$ 186	$182 \times .6 + 190 \times .3 + 138 \times .1$ = 180	$149.7 + .3 \times (182 - 149.7)$ = 159.4
7		$(182 + 177) \div 2 =$ 179.5	$177 \times .6 + 182 \times .3 + 190 \times .1$ = 179.8	$159.4 + .3 \times (177 - 159.4)$ = 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	$360 + .4 \times (348 - 360) = \mathbf{355.2}$
2017	311	$355.2 + .4 \times (372 - 355.2) = \mathbf{361.9}$
2018	371	$361.9 + .4 \times (311 - 361.9) = \mathbf{341.6}$
2019	365	$341.6 + .4 \times (371 - 341.6) = \mathbf{353.3}$
2020		$353.3 + .4 \times (365 - 353.3) = \mathbf{358.0}$



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	Error1	Forecast #2	Error2
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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3.11 KEY TERMS



Key Terms

- **Associative Model Forecasting Methods**, also known as causal or econometric forecasting methods, are quantitative techniques used in operations management to predict future values of a variable by analyzing its relationship with other related variables.
- **Correlation analysis** is often used with regression analysis to measure the strength and direction of the linear relationship between the dependent and independent variables.
- **Demand forecasts**, also known as sales forecasts, estimate consumers' future demand for a company's products or services.
- **Economic forecasts** address the overall business cycle and predict economic indicators such as housing starts, inflation rates, money supply, and others.
- **Exponential Smoothing Method** integrates the most recent actual demand and the previous forecast to generate the forecast for the upcoming period.
- **Forecasting** is the process of predicting future events or trends by analyzing historical and contemporary data.
- **Long-term forecasting**, typically encompassing a timeframe exceeding two years, is often undertaken at the strategic level of an organization.
- **Mean Absolute Deviation (MAD)** measures the average magnitude of the forecast errors without considering their direction (positive or negative).
- **Mean Absolute Percentage Error (MAPE)** is a relative measure that expresses the forecast errors as a percentage of the actual values.
- **Mean Squared Error (MSE)** is a measure that squares the forecast errors before

averaging them.

- **Medium-term forecasting**, also referred to as intermediate-term forecasting, typically spans from several months to two years into the future.
- **Naive Approach**, also known as naive forecasting or naïve method, is one of the simplest forecasting techniques used in operations management. It involves using the actual value from the previous period as the forecast for the next period without considering any other factors or patterns in the data.
- **Qualitative forecasting** techniques, unlike their quantitative counterparts, rely on subjective judgments and opinions rather than historical data.
- **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.
- **Regression analysis** involves constructing a mathematical equation that relates the dependent variable to one or more independent variables.
- **Seasonal Index** is a statistical tool used in forecasting to quantify and account for recurring seasonal patterns or demand fluctuations over a specific period.
- **Short-term forecasting** focuses on a timeframe ranging from daily to a few months. These forecasts are primarily employed for operational decision-making processes, such as inventory management, production scheduling, and workforce allocation.
- **Simple Moving Average Method** is fundamental for forecasting future values based on historical data. It operates by calculating the average of the data points from the most recent n periods.
- **Technological forecasts** monitor the rates of technological progress and trends.

CHAPTER 4: PRODUCT AND SERVICE DESIGN

Chapter Overview

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4.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Explain how firms compete in the market through new product and service design.
- Describe the steps involved in the new product development process.
- Analyze the use and benefits of the House of Quality (HOQ).
- Outline the stages of the product life cycle and their implications.
- Identify the challenges and strategic considerations at each stage of the product life cycle.

4.1 COMPETING IN THE MARKET WITH A NEW PRODUCT

In [Chapter 2](#), we explored how business firms strive to penetrate and expand their market share by enhancing their competitive advantage. To win more customers, firms must meet—and ideally, exceed—customer expectations in terms of *price, quality, variety, and timeliness*.

These values must be seamlessly integrated into the products or services offered. A firm can achieve success by introducing a novel product that competitors have not yet offered or by significantly enhancing the features of an existing product to deliver superior value to customers.

Profit-seeking firms understand that once they introduce a new product or service, competitors are likely to follow suit, impacting the popularity, pricing, and profitability of their offerings.

Therefore, firms must adopt a holistic, long-term perspective to anticipate market dynamics and understand how these changes

can affect their costs and profitability. In this chapter, we will first examine the process of developing a new product, followed by an analysis of its lifecycle, and consider the critical aspects of quality, price, and cost in this endeavour.



“Customer Expectations” by Koen Liddiard
[CC BY-NC-SA](#)

4.2 PROCESS OF NEW PRODUCT DEVELOPMENT

The New Product Development (NPD) process is a systematic sequence of activities undertaken by organizations to conceive, design, test, and evaluate the market viability of new products or services. The overarching objective of a robust NPD process is to drive organizational growth and ensure long-term sustainability by introducing offerings that meet evolving customer needs and provide a competitive advantage. This process typically involves a series of well-defined stages, as outlined below:

Step 1: Idea Generation

The first step in the new product development process is idea generation. This phase involves a systematic and continuous search for new product development opportunities. Organizations explore various sources and methods to support their ideas, aiming to identify innovative concepts that can lead to successful products. This step includes several types of analyses, each contributing uniquely to the idea generation process:

Dimensional Analysis:

Dimensional analysis examines all physical characteristics of a product, providing a comprehensive list of these attributes. This analysis helps organizations understand the fundamental aspects of their product's design and functionality. By asking questions such as "Why is the product designed this way?", "How could the product be improved?" and "What would happen if one or more characteristics were altered?" Organizations can identify potential areas for enhancement or innovation. This method encourages a deep dive into the product's physical properties, fostering creative thinking about possible modifications and improvements.

Problem Analysis:

Problem analysis focuses on identifying issues consumers face with existing products or services. Organizations conduct thorough investigations to uncover the challenges and frustrations experienced by users. By understanding these problems, organizations can develop new products that better meet consumer needs. This analysis often involves collecting feedback from customers, analyzing complaints, and studying usage patterns to pinpoint specific areas where current products fall short. The insights gained from problem analysis are crucial for designing solutions that address real-world issues, and enhancing customer satisfaction and loyalty.

Benefit Structure Analysis:

Benefit structure analysis identifies the benefits consumers seek in a product. Organizations use questionnaires and surveys to gather this information directly from customers, ensuring the new product aligns with consumer desires. This analysis involves compiling a list of desired features and benefits, which serves as a blueprint for product development. By understanding what consumers value most, organizations can prioritize these elements in their design process, creating products that resonate with their target audience. This method helps bridge the gap between consumer expectations and product offerings, leading to more successful and well-received products.

Scenario Analysis:

Scenario analysis involves assessing market opportunities for new products or services. Companies analyze current market trends, competitive landscapes, and potential future developments to understand the opportunities and challenges they may face. This analysis helps organizations anticipate changes in consumer preferences, technological advancements, and economic conditions that could impact their product's success. By exploring various scenarios, companies can develop strategic plans to navigate the complexities of the market, positioning their new products for optimal performance. Scenario analysis is a forward-looking approach that equips organizations with the insights needed to make informed decisions and capitalize on emerging opportunities.

Step 2: Idea Screening

Idea screening is the second step in the new product development process. After identifying potential ideas, it is essential for the firm to screen them to ensure only the most promising concepts move forward. During idea screening, the firm eliminates poor, unsound, unsuitable, and unattractive ideas, focusing only on feasible ideas with potential for sustainability and growth. This step is crucial for refining the pool of ideas and ensuring that resources are invested in the most viable options.

Idea Screening Questions

In the idea screening phase, companies seek answers to the following questions:

- **Will the product be beneficial for the customer in the target market?**
 - This question assesses whether the proposed product will meet the needs and preferences of the target market. Companies evaluate the potential benefits the product offers to customers, ensuring it addresses their pain points and provides value.
- **What is the current and expected future competition for the product idea?**
 - Understanding the competitive landscape is vital. Companies analyze existing competitors and anticipate future competition to determine if the product can stand out in the market. This involves studying competitors' strengths, weaknesses, and market positioning.
- **What are the industry sales and market trends on which the product idea is based?**
 - Companies examine industry sales data and market trends to gauge the potential demand for the product. This analysis helps in understanding the market dynamics and identifying growth opportunities. It includes evaluating historical sales figures, current market conditions, and future projections.
- **Is it technically feasible for the firm to manufacture such a product?**
 - Technical feasibility is a critical consideration. Companies assess whether they have the necessary technology, expertise, and resources to produce the product. This involves evaluating manufacturing capabilities, supply chain logistics, and potential technical challenges.
- **Will the product be profitable for the firm when it is manufactured and delivered to the customer at the target price?**
 - Profitability is a key factor in idea screening. Companies analyze the cost of production, pricing strategies, and potential profit margins to ensure the product will be financially viable. This includes calculating the cost of materials, labour, distribution, and marketing, as well as estimating the expected revenue.

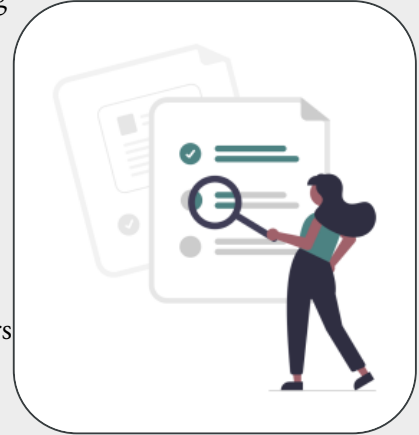


Image by [unDraw](#), [unDraw License](#).

Step 3: Concept Testing

Concept testing involves presenting the product concept to consumers to gauge their reactions and intentions at this early stage of development. This process helps companies determine whether any changes are needed before proceeding further. Concept testing is crucial for avoiding costly mistakes by identifying potential issues and areas for improvement early on. It is a quick and inexpensive method for measuring consumer enthusiasm and gathering valuable feedback.

During concept testing, companies typically seek to understand the following:

- Consumer Reactions
- Intentions to Purchase
- Suggestions for Improvement
- Perceived Value
- Market Fit

Overall, concept testing is an essential step in the new product development process, providing valuable insights that help companies refine their product concepts and increase the likelihood of market success.

Step 4: Market Strategy Development

The next step in the new product development process is market strategy development. At this stage, firms carefully define key aspects that will guide the product's entry and growth in the market. This includes determining the target market size and structure, establishing how the product will be positioned against competitors, and setting specific goals for sales, market share, and profitability for the initial years after launch.

Additionally, companies decide on the planned pricing strategy, distribution channels, and allocate a marketing budget to support the product during its introduction and early growth phases. Effective market strategy development is essential for maximizing the product's chances of success in a competitive marketplace.

Overall, market strategy development is a comprehensive process that lays the foundation for the product's successful launch and growth in the market.

Step 5: Business and Financial Analysis

Business and financial analysis is an important step in the new product development process. It involves estimating the total costs involved in developing and marketing the product, including research, production, and distribution expenses. Firms also assess how much investment they can allocate based on their financial capacity.

To evaluate profitability, companies perform cost-benefit analyses, comparing expected revenues with costs. Key financial measures such as break-even point and return on investment (ROI) help determine whether the product is financially viable.

Additionally, firms decide how to finance the project. They may use equity funds (owners' capital) or debt funds (loans from banks or other lenders), or a combination of both. The choice depends on the firm's financial strategy and resources.

In summary, business and financial analysis helps firms understand the costs, investment needs, profitability, and funding options to support successful product development.



Image by [unDraw](#), [unDraw License](#).

Step 6: Test Marketing

Test marketing is a crucial step in the new product development process. In this stage, the new product is launched on a limited scale, typically in one or more carefully selected geographic areas or market segments. The primary goal is to evaluate the product's real-world performance before committing to a full-scale launch.

Through test marketing, firms can observe how actual consumers respond to the product under normal market conditions. This process provides valuable insights into consumer behaviour, including purchase patterns, usage, and overall satisfaction. Companies can also assess the effectiveness of their marketing strategies, such as pricing, promotion, and distribution methods.

The feedback and data collected during test marketing help firms identify potential improvements or modifications needed for the product or its marketing approach. Ultimately, test marketing reduces the risks associated with a nationwide or global product launch by allowing companies to make informed decisions based on actual market reactions.

Step 7: Commercialization

Commercialization is the final and most significant step in the new product development process. Once the product has successfully passed the test marketing phase, the firm is ready to launch the product to its entire target market. This stage marks the beginning of the product's entry into the introductory phase of the product life cycle.

During commercialization, the company implements its complete marketing plan, which includes large-scale production, widespread distribution, and full-scale promotional activities. This involves coordinating efforts across various departments, such as manufacturing, sales, logistics, and customer service, to ensure a smooth and successful market introduction.

Commercialization also requires significant investment in advertising, sales promotions, and distribution channels to build product awareness and encourage consumer adoption. The company closely monitors the market response, sales performance, and customer feedback to make any necessary adjustments in strategy.

Overall, commercialization is a critical phase that determines the long-term success of the new product in the marketplace. It transforms the product from a concept into a commercially available offering, aiming to achieve strong market presence and profitability.



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4.3 HOUSE OF QUALITY IN NEW PRODUCT DEVELOPMENT

The House of Quality (HOQ) is a central tool in the Quality Function Deployment (QFD) methodology, designed to ensure that customer requirements are systematically translated into specific technical features during new product development. By providing a structured and visual planning matrix, the HOQ helps organizations connect what customers want with how those needs can be met through product design and engineering. This approach enables companies to prioritize design objectives, balance trade-offs, and make well-informed decisions throughout the development process. Figure 4.3.1 illustrates a completed House of Quality.

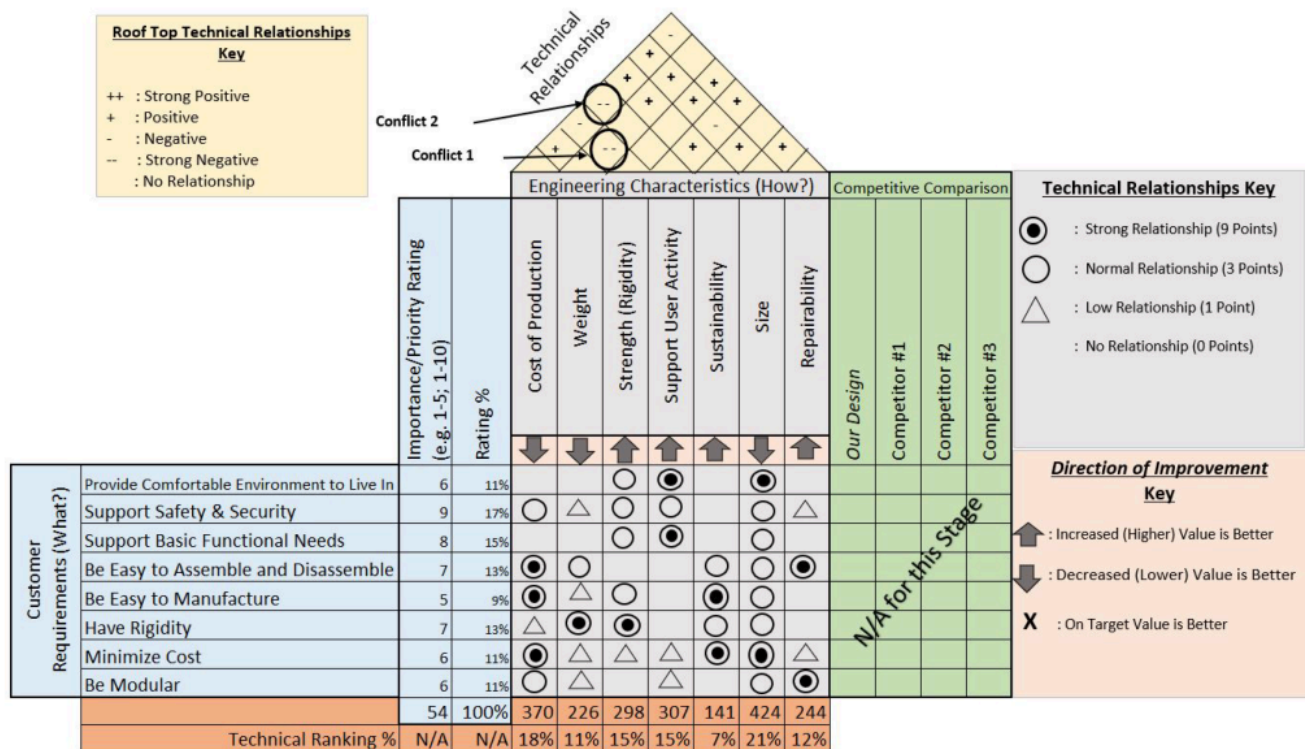
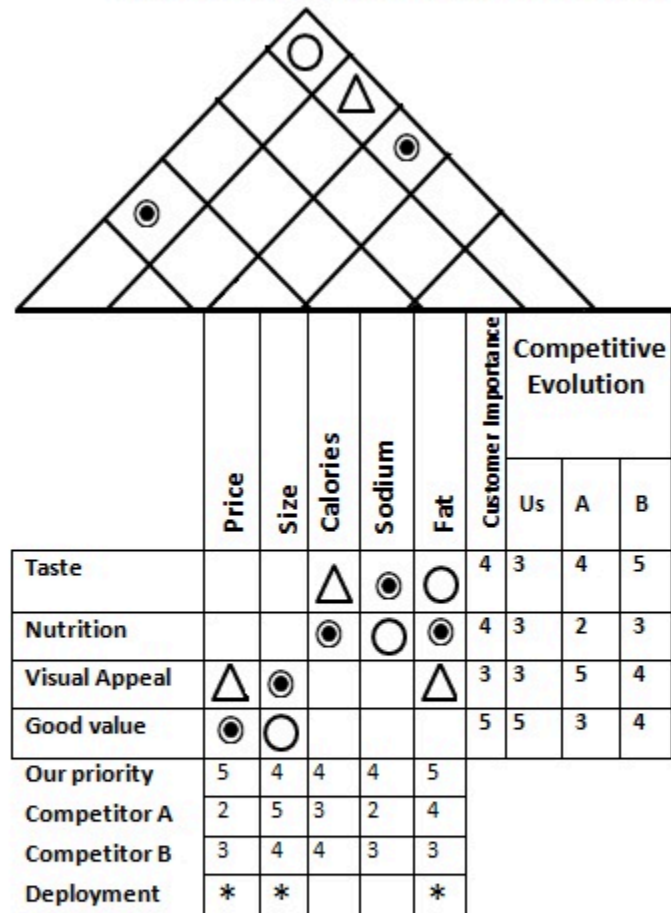


Figure 4.3.1 “QFD/HOQ” by Moran, Ertas & Gulbulak. [CC BY 4.0](#)

Example***Building the House of Quality Example*****Legend: 1 = low, 5 = high**

● Very Strong relationship

○ Strong relationship

△ Weak relationship

Figure 4.3.2 “Building the House of Quality” by [logiAsad](#), CC BY-SA 4.0



Key Components of the House of Quality

- *Customer Requirements (WHATs)*. This section lists the voice of the customer, their needs, expectations, and preferences. These are typically gathered through market research, surveys, interviews, and direct customer feedback.
- *Technical Characteristics (HOWs)*. These are the specific, measurable product features or engineering attributes that are designed to meet the customer's requirements. They represent the technical response to the WHATs.
- *Relationship Matrix*. Located at the centre of the HOQ, this matrix shows the strength of the relationship between each customer requirement and each technical characteristic. It helps identify which technical features have the most significant impact on customer satisfaction.
- *Roof (Correlation Matrix)*. The triangular “roof” at the top of the diagram displays the correlations among the technical characteristics themselves, highlighting areas where features may support or conflict with each other. This helps in identifying possible trade-offs or synergies in the design.
- *Competitive Assessment*. This section compares the company's product with those of competitors from the perspective of customer requirements. It provides valuable insights into the product's relative strengths and areas for improvement.

By using the House of Quality, companies can ensure that the voice of the customer is central to the product development process, leading to products that better satisfy market needs and stand out in competitive markets. (IONOS Editorial Team, 2020)

Benefits of Using the House of Quality

The House of Quality (HOQ) offers several significant benefits in the new product development process:

- *Customer-Centric Development*: HOQ ensures that product development is guided by actual customer needs and preferences, rather than relying on assumptions. This leads to products that are more likely to satisfy market demands and achieve commercial success.

- *Effective Resource Allocation*: By clearly identifying and prioritizing the most critical customer requirements and corresponding technical characteristics, companies can focus their resources on areas that will have the greatest impact.
- *Enhanced Cross-Functional Communication*: HOQ serves as a common framework that brings together teams from marketing, engineering, manufacturing, and other departments. This alignment improves collaboration, reduces misunderstandings, and streamlines the decision-making process.
- *Competitive Advantage*: The structured analysis provided by HOQ helps companies pinpoint opportunities to outperform competitors. By understanding both customer expectations and competitor offerings, firms can develop products with distinctive features and superior value.

Overall, the House of Quality helps organizations develop products that are better aligned with customer needs, more competitive in the marketplace, and more efficiently brought to market. (Mathias, 2023)

Implementing the House of Quality

The implementation of the House of Quality (HOQ) begins with identifying customer requirements or needs and translating these into measurable product features or technical characteristics. Next, the development team evaluates how each technical characteristic addresses the identified customer requirements and assesses how effectively competitors are meeting those same needs. Based on this analysis, the team sets specific targets or goals for each technical characteristic. The roof matrix is then used to identify potential conflicts or synergies between different technical characteristics. By following these steps, organizations can ensure that product development is closely aligned with customer expectations.

These steps are further illustrated in the following video.

Video: “[House of Quality Tutorial: How to Build a House of Quality](#)” by [Wondershare Edraw](#) [6:08] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

4.4 PRODUCT LIFE CYCLE

The product life cycle (PLC) describes the series of stages that a product goes through from its initial introduction to the market until its eventual withdrawal or discontinuation. Each product follows its own unique life cycle, which is influenced by its characteristics, market conditions, and consumer preferences. Figure 4.4.1 illustrates the typical stages of a product life cycle.

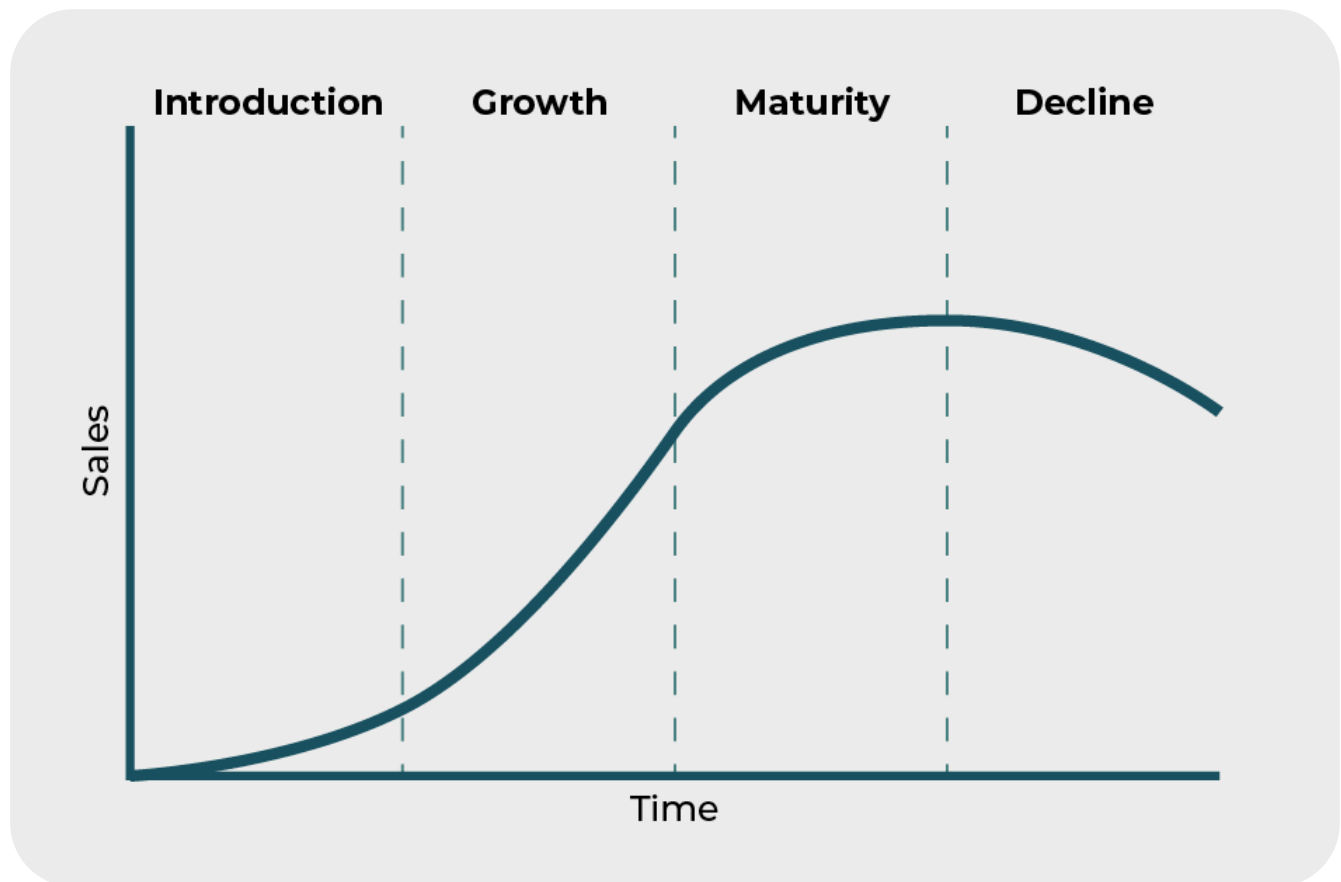


Figure 4.4.1 "[Stages of Product Life Cycle](#)" by Sudharshu Joshi, [CC BY-NC 4.0](#). Mods: Redone for clarity & recoloured.

No product can satisfy consumer needs and wants indefinitely. The longevity of a product in the market depends on its ability to meet evolving customer expectations and adapt to changing market dynamics. As a result, both sales and profits associated with a product fluctuate over time.

Understanding the product life cycle is essential for businesses, as it highlights the relationship between sales volume and profitability throughout the product's existence. The PLC framework shows key moments

in a product's journey: its introduction to the market, the phase of rapid growth and acceptance, the peak of its success, the period of decline, and finally, its exit from the market.

The main stages of the product life cycle are explained in detail in the following section.

Stages of the Product Life Cycle

The product life cycle (PLC) consists of four main stages: Introduction, Growth, Maturity, and Decline. Each stage presents unique challenges and opportunities for marketers and requires distinct strategies for success.

Introduction Stage

The introduction stage begins when a new product is launched and becomes available to consumers for the first time. At this point, consumer awareness is low, and there is little to no prior experience with the product. Companies typically invest heavily in marketing and promotional activities to create awareness and stimulate interest. Distribution is often limited, and sales grow slowly as the market learns about the product.

Key characteristics of the introduction stage include:

- Significant investment in advertising and promotion to build product awareness.
- High costs related to development, production, and marketing, often resulting in losses or minimal profits.
- Limited competition, as few firms have entered the market.
- Low sales volume, with gradual growth as consumers begin to adopt the product.
- Pricing strategies may vary; some firms set higher prices to recover development costs, while others may use penetration pricing to attract customers.
- Technical and production challenges may arise and require attention.

Growth Stage

During the growth stage, the product gains market acceptance, and sales increase rapidly. Consumer awareness and demand rise, leading to higher profits. As the product's success becomes evident, competitors are attracted to the market, intensifying competition.

Key characteristics of the growth stage include:

- Rapid increase in sales and profitability due to growing consumer acceptance.
- Entry of new competitors, resulting in heightened competition.
- Expansion of distribution networks to reach more customers.
- Potential price reductions to attract price-sensitive buyers and defend market share.
- Ongoing promotional efforts to differentiate the product and maintain momentum.
- Product improvements and the introduction of new features to address customer feedback.
- Entry into new market segments and distribution channels.

Maturity Stage

The maturity stage is marked by a slowdown in sales growth as the product reaches widespread market acceptance. The market becomes saturated, and competition is intense. Profits begin to decline due to price competition and increased marketing expenses.

Key characteristics of the maturity stage include:

- Sales continue to grow but at a decreasing rate, eventually stabilizing.
- Profits decline as competition intensifies and price wars emerge.
- Marginal competitors may exit the market.
- Emphasis shifts to customer retention and loyalty.
- Companies often modify the product, explore new markets, or adjust the marketing mix to sustain sales.
- The maturity stage can be further divided into phases: growth maturity (sales growth slows), stable maturity (sales plateau), and decline maturity (sales begin to fall).

Decline Stage

In the decline stage, sales and profits decrease as the product loses relevance or is replaced by newer innovations. Consumer preferences shift, and the market contracts. Companies must decide whether to withdraw the product, reduce costs, or attempt to revitalize it.

Key characteristics of the decline stage include:

- Rapid decline in sales and a sharper decline in profits.
- Firms may discontinue the product, reduce promotional expenses, or focus on profitable segments.
- Remaining competitors may exit the market, while some firms continue with minor product modifications.
- Resources are often shifted to newer, more promising products.
- Cost control becomes a priority to maintain any remaining profitability.

Understanding these stages helps businesses develop effective strategies for managing products throughout their life cycle, from introduction to eventual withdrawal.

Significance of the Product Life Cycle

Product life cycle (PLC) analysis is crucial for the long-term success and competitiveness of a firm's products. By systematically evaluating which stage a product occupies within its life cycle, companies can gain valuable insights into the product's current market position and overall health.

Effective PLC analysis enables firms to anticipate shifts in consumer preferences and identify emerging market trends. This awareness allows companies to proactively adapt their marketing strategies, adjust pricing, modify product features, or explore new distribution channels in response to changing market conditions.

Moreover, understanding the product life cycle helps organizations allocate resources more efficiently, plan for product updates or discontinuation, and develop strategies to extend the profitable life of their offerings. Ultimately, PLC analysis supports informed decision-making, enhances a firm's ability to respond to market dynamics, and increases the likelihood of sustained success in competitive environments.

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4.5 LIFE CYCLE COST IN NEW PRODUCT DEVELOPMENT

Life Cycle Cost (LCC) analysis is a strategic methodology employed in new product development to evaluate the total cost of ownership over the entire lifespan of a product. This comprehensive approach encompasses all costs incurred from the initial concept through to final disposal, enabling informed decision-making that aligns with long-term financial and operational objectives.

By integrating LCC analysis into the design and development process, organizations can optimize resource allocation, enhance sustainability, and improve cost-efficiency. The methodology encourages a shift from short-term cost considerations to a holistic view of economic impact throughout the product's life cycle.



Key Components of Life Cycle Cost

LCC analysis typically includes the following five core components:



1. **Research and Development (R&D):**

This phase includes all expenditures related to the conceptualization, design, prototyping, and testing of the product. It encompasses feasibility studies, engineering design, and validation processes.

2. **Production:**

Costs incurred during the manufacturing phase, including raw materials, direct and indirect labour, equipment usage, and overheads. This component also considers economies of scale and process optimization.

3. **Distribution:**

Encompasses the logistics of delivering the product to the market. This includes packaging, transportation, warehousing, and inventory management.

4. **Usage:**

Refers to the operational costs borne by the end-user. These may include energy consumption, routine maintenance, repairs, and any ancillary services required during the product's operational life.

5. **End-of-Life (EOL):**

Covers the costs associated with the product's disposal, recycling, or decommissioning. This phase is increasingly important in the context of environmental regulations and sustainability goals.

Importance of Life Cycle Cost (LCC) in Product Development

Life Cycle Cost (LCC) analysis plays a pivotal role in modern product development by offering a comprehensive framework for evaluating the total cost implications of a product throughout its entire life span. This methodology delivers valuable insights that address the strategic concerns of the designing firm, environmental sustainability, and customer value as briefly examined hereunder.

1. *Strategic Value for the Firm:* For product developers and decision-makers within a firm, LCC provides a holistic cost assessment that extends beyond the immediate expenses of production. By incorporating costs from research and development through to end-of-life disposal, LCC enables a more accurate estimation of a product's financial impact. This broader perspective supports informed decision-making, allowing designers and managers to prioritize long-term value creation over short-term cost minimization.
2. *Environmental Considerations:* LCC analysis also contributes to environmentally responsible design. By accounting for end-of-life costs, such as recycling, disposal, or decommissioning, designers are encouraged to consider the environmental consequences of their choices. This fosters the development of products that are not only economically viable but also aligned with sustainability goals and regulatory requirements.
3. *Enhanced Customer Value:* From the customer's perspective, LCC emphasizes the total cost of ownership rather than just the initial purchase price. This includes operational, maintenance, and disposal costs, which can significantly influence the perceived value of a product over time. By integrating these considerations into product development, firms can deliver solutions that offer greater long-term value, thereby enhancing customer satisfaction and competitive advantage.

Video: "[How to Calculate the Life Cycle Cost](#)" by [Edspira](#) [1:47] is licensed under the [Standard YouTube License](#). Transcript and closed captions available on YouTube.

Implementing LCC Analysis in Product Development

The effective integration of Life Cycle Cost (LCC) analysis is paramount in the development of both products and services. To achieve this, the following sequential steps are crucial:

The integration of Life Cycle Cost (LCC) analysis into product and service development is essential for achieving sustainable, cost-effective, and value-driven outcomes. Effective implementation of

LCC ensures that all financial implications are considered throughout the product's life span, from conception to disposal. The following structured steps outline a systematic approach to embedding LCC analysis within the development process:

1

Defining the Scope: Establish a clear framework for the analysis by identifying the stages of the product life cycle to be evaluated. This includes specifying which cost elements—such as development, production, operation, and end-of-life—will be included in the assessment.

2

Gathering Data: Collect accurate and comprehensive cost data for each identified life cycle stage. This may involve historical data, market research, supplier quotes, and expert estimates to ensure reliability and relevance.

3

Developing Cost Models: Construct predictive models that estimate costs over the product's expected lifespan. These models should account for variables such as inflation, usage patterns, maintenance schedules, and technological obsolescence.

4

Analyzing Alternatives: Evaluate multiple design or development options by comparing their total life cycle costs. This comparative analysis supports the selection of solutions that offer the best balance between performance and cost-efficiency.

5

Making Trade-off Decisions: Use LCC insights to make informed trade-offs between initial investment and long-term operational costs. This step is critical in optimizing overall value rather than focusing solely on upfront expenditures.

6

Review and Update: Continuously refine the LCC analysis as new data becomes available throughout the development process. Iterative updates ensure that the analysis remains accurate and aligned with evolving project parameters.

These steps not only enhance the financial and environmental sustainability of product development but also play a critical role in strategic pricing decisions, as discussed in the subsequent section.

4.6 TOTAL LIFE CYCLE COST AND PRODUCT PRICING

The **Total Life Cycle Cost (TLCC)** is a critical determinant in setting the price of a product. Unlike traditional pricing strategies that focus primarily on production costs, TLCC encompasses all costs incurred throughout the product's life span—from research and development to end-of-life disposal. This comprehensive approach ensures that pricing decisions not only cover all associated costs but also secure a sustainable profit margin.



Illustrative Example: The “Ultra Coffee Pot”

Consider a manufacturer developing a high-end commercial coffee maker, the Ultra Coffee Pot, intended for use in cafés. The product is designed with a 5-year lifespan, and the following cost structure is projected:

- *Research and Development (R&D)*: \$500,000 (one-time)
- *Production Volume*: 1,000 units over 5 years
- *Per Unit Costs*:
 - Materials: \$200
 - Labour: \$100
 - Overhead: \$50
- *Support Costs*: \$40 per unit (2-year warranty and customer service)
- *End-of-Life Costs*: \$20 per unit (recycling/disposal)

Step 1: Calculating Total Life Cycle Cost (TLCC)

R&D Cost/unit	$\$5,00,000 / (1000\text{unit} * 5 \text{ years})$	\$100/unit
Material		
Labour		
Overhead		
Total Manufacturing Cost		\$350/unit
Marketing		
Distribution		
Total M&D COST		\$80/unit

Support&Warranty COST	$\$40 \times 2\text{yrs} =$	\$80/unit
Recycling and Disposal	$\$20/\text{unit}$	\$20/unit
TLCC		\$630/unit

Step 2: Determining Minimum Selling Price

To achieve a 25% *profit margin*, the minimum selling price is calculated as:

$$\text{Minimum Price} = \frac{\text{TLCC}}{1 - \text{Profit Margin}} = \frac{630}{1 - 0.25} = \$840$$

This price falls within the competitive market range of \$800–\$1,000 for similar high-end commercial coffee makers.

Step 3: Strategic Pricing Decision

The manufacturer may choose to price the product at \$899, which is near the midpoint of the market range. This decision has several implications:

- *Cost Coverage:* The price of \$899 fully covers the TLCC of \$630.
- *Profit Margin:*

$$\begin{aligned}\text{Profit} &= 899 - 630 = \$269 \\ \text{Profit Margin} &= \frac{269}{899} \approx 29.9\%\end{aligned}$$

- *Competitive Positioning:* The product remains competitively priced while ensuring a healthy return.

Strategic Implications of TLCC-Based Pricing

- *Long-Term Viability:* By accounting for all lifecycle costs, the firm ensures financial sustainability and product support throughout its operational life.
- *Customer Value Proposition:* The price can be justified by emphasizing the product's durability, quality, and included services (e.g., warranty and support).
- *Sensitivity Analysis:* TLCC-based pricing allows for proactive adjustments in response to cost fluctuations. For instance:
 - A 10% increase in material costs raises the TLCC to \$650, requiring a new price of: $650 / (1 - 0.25) = \$867$
 - If support costs rise to \$50 per unit, TLCC again becomes \$650, necessitating similar pricing adjustments.

4.7 TOTAL ACQUISITION COST

Individuals and business entities procure products at a specific price to fulfill operational or consumption needs. However, the true economic burden of acquiring these products often extends beyond the initial transaction value. **Total Acquisition Cost (TAC)** represents a holistic measure of all expenditures incurred in obtaining an asset or securing a customer relationship. It transcends the stated purchase price to encompass the entirety of costs associated with rendering the asset operational or onboarding a new customer.

Beyond the direct purchase price, TAC can incorporate a diverse range of supplementary expenses, including but not limited to:

- Transportation and shipping logistics
- Installation and setup procedures
- Personnel training requirements for operation or utilization
- Initial inventory of necessary supplies or materials
- Legal and administrative overheads related to the acquisition
- Customization or modification expenses to meet specific requirements



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To establish a more robust understanding of Total Acquisition Cost, it may be beneficial to first examine the concept of Total Ownership Cost before proceeding with illustrative examples. This foundational understanding will provide a broader context for appreciating the nuances embedded within the acquisition phase of an asset's or customer's lifecycle.

4.8 TOTAL OWNERSHIP COST

Consumers and business firms purchase products at a specific price to fulfill operational or consumption needs. However, the true economic burden associated with a product extends beyond its initial purchase price. Once a product is acquired, the owner incurs additional costs throughout its lifecycle. These supplementary expenses, combined with the purchase price, constitute the **Total Ownership Cost (TOC)**, also known as Total Cost of Ownership (TCO).

TOC encompasses a wide range of direct and indirect costs, including:



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- **Operating Costs:** Ongoing expenses related to the product's function, such as energy or fuel consumption.
- **Maintenance and Repair Costs:** Expenditures required to keep the product in working order.
- **Upgrade Costs:** Expenses associated with enhancing the product's capabilities or extending its lifespan.
- **Depreciation:** The reduction in the product's value over time.
- **Training Costs:** Expenses related to educating personnel on the product's proper use.
- **Disposal Costs:** Expenses incurred at the end of the product's useful life.

The following video provides a concise overview of the Total Cost of Ownership concept:

Video: "[How to Calculate the Total Cost of Ownership](#)" by [Edspira](#) [1:34] is licensed under the [Standard YouTube License](#). Transcript and closed captions available on YouTube.

The Total Cost of Ownership (TCO) is a financial estimate that helps consumers and enterprise managers determine the direct and indirect costs of a product or system over its entire lifecycle. The following example explains TCO for a small manufacturing firm



Example: Medway Metal Products – Press Machine Acquisition

Medway Metal Products has recently acquired a specialized press machine for a purchase price of \$100,000. In addition to this initial cost, several other acquisition-related expenses were incurred: \$2,000 for legal review of the contract, \$5,000 for shipping and handling, \$10,000 for on-site installation, \$7,000 for customization to meet specific production requirements, and \$3,000 for initial operator training. The projected lifecycle of this machine is five years, at the end of which its disposal is estimated to cost \$5,000. Due to the machine's specialized application, beyond the annual routine maintenance cost of \$3,000, a significant recalibration and upgrade costing \$15,000 will be required in the third year of operation. The machine's operation will also incur annual costs of \$5,000 for energy consumption and \$10,000 for specific custom materials. Furthermore, ongoing training for new operators is estimated at \$1,000 per year. The objective is to determine the Total Cost of Ownership (TCO) for this press machine over its five-year lifecycle.

The Total Cost of Ownership (TCO) is calculated by aggregating the Total Acquisition Cost (TAC) and all subsequent operational and end-of-life costs.

Total Acquisition Cost (TAC):

TAC = Purchase Price + Legal Fees + Shipping

+ Installation + Customization + Initial Training

TAC = \$100,000 + \$2,000 + \$5,000 + \$10,000 + \$7,000 + \$3,000

TAC = \$127,000

Usage Costs (Operational and End-of-Life Costs):

Usage costs include all expenses associated with owning and operating the machine throughout its lifecycle, including disposal.

$$\begin{aligned}
 \text{Usage Costs} &= (\text{Annual Energy Cost} + \text{Annual Material Cost}) \times \text{Lifecycle (Years)} \\
 &\quad + (\text{Annual Maintenance Cost} \times \text{Lifecycle (Years)}) \\
 &\quad + (\text{Annual New Operator Training Cost} \times \text{Lifecycle (Years)}) \\
 &\quad + \text{Upgrade Cost} + \text{Disposal Cost} \\
 \text{Usage Costs} &= (\$5,000 + \$10,000) \times 5 + (\$3,000 \times 5) + (\$1,000 \times 5) \\
 &\quad + \$15,000 + \$5,000 \\
 \text{Usage Costs} &= \$75,000 + \$15,000 + \$5,000 + \$15,000 + \$5,000 \\
 \text{Usage Costs} &= \$115,000
 \end{aligned}$$

Total Cost of Ownership (TCO):

The TCO is the sum of the Total Acquisition Cost and the total Usage Costs over the asset's lifecycle.

$$\begin{aligned}
 \text{TCO} &= \text{TAC} + \text{Usage Costs} \\
 \text{TCO} &= \$127,000 + \$115,000 \\
 \text{TCO} &= \$242,000
 \end{aligned}$$

Therefore, the Total Cost of Ownership for the Medway Metal Products press machine over its five-year lifecycle is \$242,000. This comprehensive figure provides a more accurate understanding of the long-term financial implications of this capital investment compared to solely considering the initial purchase price.

Comparing TAC and TOC

Total Acquisition Cost (TAC) and Total Ownership Cost (TOC) represent distinct but complementary perspectives on the financial implications of acquiring and utilizing an asset. **TAC** primarily focuses on the initial, upfront expenditures associated with obtaining an asset or a customer. In contrast, **TOC** provides a more encompassing view of all costs accrued throughout the entire lifecycle of the asset, extending beyond the initial acquisition phase to include operational, maintenance, and disposal expenses.

The strategic application of both TAC and TOC metrics enables more informed and robust decision-making processes. TAC is particularly valuable for immediate budgetary planning and for conducting comparative analyses of the initial capital outlays required for different acquisition options. Conversely, TOC is instrumental in long-term financial planning and can reveal scenarios where a seemingly higher initial investment (leading to a higher TAC) may ultimately result in lower overall costs over the asset's lifespan due to factors such as reduced operating expenses, lower maintenance requirements, or enhanced durability.

To further elucidate this concept, consider a comparative analysis of the press machine example from Medway Metal Products (Machine A) with an alternative machine (Machine B) that presents a different cost profile. Machine A had a TAC of \$127,000 and a TOC of \$242,000 over five years.

Let’s assume Machine B has a higher acquisition cost (\$150,000 TAC) but significantly lower usage costs of **\$80,000** over five years due to superior energy efficiency and reduced maintenance needs.

Cost Component	Machine A	Machine B
Total Acquisition Cost (TAC)	\$127,000	\$127,000
Total Usage Costs	\$115,000	\$80,000
Total Ownership Cost (TOC)	\$242,000	\$230,000

In this revised scenario, while Machine B has a higher initial TAC, its lower usage costs result in a lower overall TOC (\$230,000) compared to Machine A’s \$242,000 over the five-year period. This demonstrates how focusing solely on the initial purchase price (TAC) could lead to a suboptimal long-term financial decision.

By strategically considering both TAC and TOC, businesses can make more judicious decisions that effectively balance short-term budgetary constraints with the imperative of long-term financial efficiency and overall value creation.

Video: “[Life Cycle Costing](#)” by [Angie Rodriguez](#) [5:42] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

4.9 CHAPTER SUMMARY & REVIEW



Summary

This chapter discusses the importance of product and service design as a driver of competitive advantage. It introduces the new product development (NPD) process, which includes idea generation, idea screening, concept testing, market strategy development, business and financial analysis, test marketing, and commercialization. Each step is intended to ensure that products align with customer expectations, are technically and financially feasible, and achieve market success. The chapter also highlights the House of Quality (HOQ) as a tool to translate customer requirements into technical features, ensuring customer-centred design and effective cross-functional collaboration.

The chapter further examines the product life cycle (PLC)—introduction, growth, maturity, and decline—outlining the strategic implications of each stage for sales, profitability, and competition. It stresses the importance of Life Cycle Cost (LCC) analysis, which evaluates total ownership costs from R&D through end-of-life, enabling firms to make informed design, pricing, and sustainability decisions. Concepts such as Total Acquisition Cost (TAC) and Total Ownership Cost (TOC) are introduced to help firms balance short-term and long-term financial considerations. Through frameworks, examples, and case studies, the chapter demonstrates how integrating customer needs, cost analysis, and strategic planning leads to innovative, sustainable, and competitive products.

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Review Questions

1. Why is aligning new product and service design with customer values critical for gaining a competitive advantage in today's market?
2. The chapter outlines several techniques for idea generation (dimensional, problem, benefit structure, and scenario analyses). Which of these do you think is most effective, and why?
3. What role does idea screening play in the new product development process, and what risks might a company face if this step is rushed or overlooked?
4. How does concept testing with consumers reduce the risk of product failure? Can you think of an example where concept testing might have prevented a real-world product failure?
5. Discuss the importance of developing a clear market strategy before launching a new product. What key elements should be prioritized?
6. In what ways does the House of Quality (HOQ) help bridge the gap between customer needs (WHATs) and technical design features (HOWs)?
7. Compare the stages of the product life cycle (PLC). How do sales, profits, and competition typically change from the introduction stage through to decline?
8. Why is Life Cycle Cost (LCC) analysis more valuable than focusing only on production costs when designing a product? Provide an example where LCC could influence a firm's decision.
9. Explain the difference between Total Acquisition Cost (TAC) and Total Ownership Cost (TOC). How can considering both help businesses make better long-term

decisions?

10. Reflecting on the case studies in the chapter, how do the principles of NPD, HOQ, and PLC apply differently across industries (e.g., fitness trackers, hydrogen fuel vehicles, or interactive fitness platforms)?

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create ten discussion questions based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

4.10 CASE STUDIES



Case Study 1: Health Watcher – New Wearable Fitness Tracker

Health Watcher, a nascent company focused on medical and rehabilitation product design and development, is poised to launch its first consumer product: a wearable fitness tracker. As a consultant, you've been tasked with guiding them through the initial stages of this launch, specifically focusing on the new product development process and translating customer needs into tangible technical specifications.

A) Outline the steps the company should follow in the new product development process.

Dimensional analysis examines all physical characteristics of a product, providing a comprehensive list of these attributes. This analysis helps organizations understand the fundamental aspects of their product's design and functionality. By asking questions such as "Why is the product designed this way?", "How could the product be improved?" and "What would happen if one or more characteristics were altered?" Organizations can identify potential areas for enhancement or innovation. This method encourages a deep dive into the product's physical properties, fostering creative thinking about possible modifications and improvements.

For a successful launch, Health Watcher should follow a structured new product development (NPD) process. Here's a recommended outline:

Phase 1: Idea Generation

Internal Idea Sources:

- Brainstorming sessions with Health Watcher's design, development, and potentially early marketing teams. Leverage their expertise in medical and rehabilitation to identify unmet needs or opportunities in the fitness tracking market.

External Idea Sources:

- **Market Research:** Analyze existing fitness trackers, their features, pricing, and user reviews to identify gaps and potential differentiators.
- **Customer Feedback (Preliminary):** Conduct initial surveys or interviews with potential users (fitness enthusiasts, individuals undergoing rehabilitation, health-conscious consumers) to understand their pain points and desired features.
- **Competitive Analysis:** Scrutinize competitors' strengths and weaknesses to identify areas where Health Watcher can offer a unique value proposition.
- **Technological Scouting:** Explore new sensor technologies, materials, and software capabilities that could be incorporated into the tracker.

Phase 2: Idea Screening

- **Initial Screening Criteria:** Develop a set of criteria to evaluate the generated ideas. These might include:
- **Strategic Fit:** Does the product align with Health Watcher's mission and capabilities in medical and rehabilitation?
- **Market Potential:** Is there a sufficiently large and addressable market for the product?
- **Feasibility:** Can Health Watcher realistically design, develop, and manufacture the product with its resources and expertise?
- **Profitability:** Does the idea have the potential to be financially viable?
- **Idea Filtering:** Apply the screening criteria to filter out unpromising ideas and

focus on the most viable concepts.

Phase 3: Concept Development and Testing

- **Product Concept Development:** Develop detailed descriptions and visual representations (mockups, sketches) of the potential fitness tracker. This includes outlining its core features, functionalities, and target user profile.
- **Concept Testing:** Present the product concepts to a sample of potential customers to gauge their reactions, identify areas for improvement, and assess purchase intent. Gather feedback on features, design, and perceived value.

Phase 4: Marketing Strategy Development

- **Target Market Definition:** Clearly identify the specific segments of consumers Health Watcher will target (e.g., active seniors, individuals in post-rehabilitation, general fitness enthusiasts).
- **Value Proposition Definition:** Articulate the unique benefits and value the Health Watcher tracker will offer to the target market compared to competitors.
- **Marketing Mix Strategy (Preliminary):** Outline initial ideas for the product (features, design), pricing, distribution channels, and promotion strategies.

Phase 5: Business Analysis

- **Demand Forecasting:** Estimate potential sales volume based on market research and concept testing.
- **Cost Analysis:** Project development costs, manufacturing costs, marketing expenses, and operational costs.
- **Profitability Analysis:** Evaluate the financial viability of the product by forecasting revenues, costs, and potential return on investment.
- **Risk Assessment:** Identify potential risks (e.g., technological challenges, competitive response, regulatory hurdles) and develop mitigation strategies.

Phase 6: Product Development

- **Prototype Development:** Create functional prototypes of the fitness tracker, incorporating feedback from concept testing and technical considerations.
- **Alpha and Beta Testing:** Conduct internal (alpha) and external (beta) testing of the prototypes to identify bugs, usability issues, and areas for refinement. Gather user feedback on real-world usage.
- **Design and Engineering:** Finalize the product design, hardware components, and software algorithms based on testing results.
- **Manufacturing Process Development:** Establish efficient and cost-effective manufacturing processes.

Phase 7: Test Marketing

- **Limited Launch:** Introduce the product in a small geographic area or to a specific group of users to gather real-world market feedback on the complete marketing mix (product, price, place, promotion).
- **Performance Monitoring:** Track key metrics such as sales, customer satisfaction, and distribution effectiveness.
- **Refinement and Adjustment:** Based on test market results, make necessary adjustments to the product, marketing strategy, or launch plan.

Phase 8: Commercialization

- **Full-Scale Launch:** Introduce the product to the broader target market through chosen distribution channels.
- **Marketing and Sales Execution:** Implement the developed marketing and sales strategies.
- **Post-Launch Monitoring and Evaluation:** Continuously track sales, market share, customer feedback, and profitability. Identify areas for ongoing improvement and potential product line extensions.

B) Identify at least three customer requirements and show how the House of Quality could be used to translate these into technical features.

Based on Health Watcher's focus on medical and rehabilitation, potential customer requirements for their fitness tracker could include:

1. **Accurate Health Monitoring:** Users, especially those with health concerns or in rehabilitation, will prioritize accurate tracking of vital signs and activity levels.
2. **User-Friendly Interface:** The device and its accompanying app should be easy to understand and navigate, particularly for individuals who may not be tech-savvy or are dealing with health-related fatigue.
3. **Comfort and Durability:** The tracker needs to be comfortable to wear for extended periods and durable enough to withstand daily activities and potential accidental bumps.

Now, let's see how the House of Quality (HOQ) can translate these customer requirements into technical features:

House of Quality Matrix (Simplified)

Explanation of the HOQ Components:

- **WHATs (Customer Requirements):** The left side lists the identified customer requirements with their assigned importance ratings (e.g., on a scale of 1 to 5, where 5 is most important).
- **HOWs (Technical Features):** The top row lists the technical features that Health Watcher can incorporate into the tracker to address the customer's requirements. These are measurable or designable characteristics.
- **Relationship Matrix:** The central matrix shows the relationship between each customer requirement and each technical feature. Symbols or numerical values indicate the strength of the relationship (e.g., strong, medium, weak, or no relationship).
- **Importance Rating (Absolute):** This is calculated by multiplying the importance of each customer requirement by the strength of its relationship to each technical feature and summing the results for each technical feature column. This helps prioritize which technical features are most critical to meeting customer needs.
- **Target Values:** These specify the desired performance level or characteristic for

each technical feature (e.g., heart rate accuracy within ± 2 BPM).

- **Units:** The units of measurement for the target values.
- **Competitive Assessment:** This section allows Health Watcher to compare its planned technical features against those of key competitors based on customer perceptions.
- **Roof (Correlation Matrix):** The triangular matrix at the top helps identify potential positive or negative correlations between the technical features. This can highlight trade-offs that need to be considered during the design process (e.g., making the casing very durable might increase its weight, impacting comfort).

How the HOQ Translates Customer Needs:

The HOQ visually demonstrates how customer requirements are directly linked to specific technical features. For example:

- “Accurate Health Monitoring” (WHAT) is strongly related to “High-Precision Heart Rate Sensor” and “Advanced Activity Recognition Algorithms” (HOWs). The HOQ quantifies this relationship and highlights the target accuracy levels needed.
- “User-Friendly Interface” (WHAT) is addressed by technical features like “Large, High-Contrast Display” and “Intuitive Mobile App Navigation” (HOWs), with target specifications focusing on screen size and ease of use.
- “Comfort and Durability” (WHAT) is linked to “Lightweight and Flexible Material” and “Sweat and Water Resistance (IP67)” (HOWs), with target values specifying weight limits and water resistance ratings.

By completing the House of Quality, Health Watcher can gain a clear understanding of which technical features are most important to their customers and how to prioritize their design and development efforts to create a successful and customer-centric fitness tracker. This framework helps ensure that the product development remains aligned with the voice of the customer.



Case Study 2: Developing a Fuel-Efficient Vehicle (Based on Hydrogen Fuel Cell Vehicle Example)

A) Steps in the New Product Development Process:

- **Idea Generation:** Focus on eco-friendly vehicles using alternative energy sources (e.g., hydrogen fuel cells).
- **Idea Screening:** Assess the feasibility of hydrogen technology, infrastructure needs, and regulatory requirements.
- **Concept Development and Testing:** Develop vehicle prototypes, test for efficiency, safety, and consumer acceptance.
- **Market Strategy Development:** Target environmentally conscious consumers and regions with supporting infrastructure.
- **Business Analysis:** Calculate development costs, expected sales, government incentives, and long-term profitability.
- **Product Development:** Engineer the vehicle, integrate hydrogen storage, fuel cell stacks, and electric drive systems.
- **Test Marketing:** Deploy a fleet for pilot programs in select cities to monitor performance and gather feedback.
- **Commercialization:** Launch the vehicle with marketing focused on sustainability and cost savings.

B) House of Quality Example:

Customer Requirement	Technical Feature
High fuel efficiency	Advanced fuel cell system
Fast refueling	High-pressure hydrogen tanks
Safety	Reinforced hydrogen storage, safety sensors

- **High fuel efficiency** leads to optimizing the fuel cell and drivetrain.
- **Fast refuelling** requires advanced tank design and compatible infrastructure.
- **Safety** results in robust storage solutions and real-time monitoring systems.



Case Study 3: Creating an Interactive Home Fitness Platform (Peloton Example)

A) Steps in the New Product Development Process:

- **Idea Generation:** Combine exercise equipment with live-streamed classes and interactive features.
- **Idea Screening:** Evaluate the demand for at-home fitness solutions and the technical feasibility of streaming integration.
- **Concept Development and Testing:** Build prototypes of the exercise bike/treadmill with screens; test with fitness enthusiasts.
- **Market Strategy Development:** Target busy professionals and fitness enthusiasts seeking convenience and community.
- **Business Analysis:** Analyze subscription revenue potential, hardware costs, and scalability.
- **Product Development:** Finalize hardware and software integration, develop a content library, and build a user-friendly interface.
- **Test Marketing:** Launch a beta program to gather user feedback on both hardware and digital experience.
- **Commercialization:** Full-scale launch with marketing focused on the unique combination of equipment, content, and community.

b) House of Quality Example:

Customer Requirement	Technical Feature
Immersive class experience	High-definition touchscreen, quality speakers
Real-time performance tracking	Integrated sensors, live data analytics
Community interaction	Social features in software, leaderboard integration

- **Immersive class experience** leads to investing in display and audio technology.
- **Real-time performance tracking** requires robust sensor integration and data

processing.

- **Community interaction** drives the development of software features for social engagement and competition.

Summary Table: House of Quality Mapping

Case Study	Customer Requirement	Technical Feature(s)
Fitness Tracker	Accurate heart rate	Advanced optical sensors
	Long battery life	Low-power chips, large battery
	Comfort	Lightweight, ergonomic materials
Fuel-Efficient Car	High fuel efficiency	Advanced fuel cell system
	Fast refueling	High-pressure tanks
	Safety	Reinforced storage, safety sensors
Interactive Fitness	Immersive experience	HD touchscreen, quality speakers
>Platform (Peloton)	Real-time tracking	Integrated sensors, analytics
	Community interaction	Social software features, leaderboards

These examples illustrate how the new product development process and the House of Quality framework are applied across diverse industries to translate customer needs into actionable technical features, ensuring the final product delivers real value and competitive differentiation.

4.11 KEY TERMS



Key Terms

- **Break-even Point:** The level of sales at which total revenues equal total costs, resulting in neither profit nor loss.
- **Business and Financial Analysis:** The evaluation of development, marketing, and operational costs against potential revenues to assess a product's financial viability.
- **Commercialization:** The full-scale launch of a new product to the target market, including widespread production, distribution, and promotional efforts.
- **Concept Testing:** A method of presenting a product idea to potential customers to assess reactions, purchase intent, perceived value, and suggestions for improvement.
- **Cost-Benefit Analysis:** A financial tool that compares the benefits of a proposed product or decision against its associated costs.
- **Customer Requirements (WHATs):** Statements that reflect the voice of the customer, expressing their needs and preferences in product features.
- **Decline Stage:** The phase in the product life cycle where sales and profits fall due to obsolescence or changing consumer preferences.
- **Dimensional Analysis:** An idea generation technique that examines a product's physical attributes to identify opportunities for improvement or innovation.
- **Distribution (LCC Component):** All logistical costs associated with delivering the product to the customer, including packaging, shipping, and inventory.
- **End-of-Life (LCC Component):** Costs incurred during product disposal, recycling, or decommissioning, often influenced by sustainability practices.

- **Growth Stage:** The product life cycle phase where sales increase rapidly, consumer awareness grows, and competitors begin to enter the market.
- **House of Quality (HOQ):** A structured matrix used in Quality Function Deployment (QFD) to link customer requirements with technical specifications in product development.
- **Idea Generation:** The initial step in NPD involving the creative search for innovative product ideas using structured methods such as problem and scenario analysis.
- **Idea Screening:** The process of filtering out weak, impractical, or unsustainable product ideas to focus resources on those with high potential.
- **Implementation of LCC Analysis:** A step-by-step process involving scope definition, data collection, cost modeling, and trade-off decisions to evaluate a product's total cost of ownership.
- **Introduction Stage:** The first phase of the product life cycle when a new product is introduced, awareness is low, and marketing investment is high.
- **Life Cycle Cost (LCC):** The total cost of a product throughout its life, from research and development to disposal, used to assess long-term cost efficiency.
- **Maturity Stage:** The product life cycle stage marked by slowed sales growth, intense competition, and strategic efforts to retain customers and maintain profitability.
- **Market Strategy Development:** The formulation of a marketing plan that includes targeting, positioning, pricing, promotion, and distribution strategies for a new product.
- **Operating Costs (TOC):** Day-to-day expenses associated with the use of a product, such as energy consumption or routine maintenance.
- **Problem Analysis:** An idea generation method that identifies deficiencies in existing products to create better alternatives based on customer pain points.
- **Product Life Cycle (PLC):** A model that describes the stages a product goes through: Introduction, Growth, Maturity, and Decline.
- **Production (LCC Component):** All costs related to manufacturing a product, including materials, labour, equipment, and overhead.
- **Profit Margin:** The percentage of revenue that exceeds the total cost,

representing the profitability of a product or service.

- **Relationship Matrix:** A central component of the House of Quality that shows the strength of relationships between customer needs and technical features.
- **Research and Development (R&D) (LCC Component):** Initial expenditures for designing, prototyping, and testing a product before market launch.
- **Return on Investment (ROI):** A profitability metric that measures the gain or loss generated on an investment relative to its cost.
- **Scenario Analysis:** An idea generation method that explores future market conditions, competitive dynamics, and trends to identify new product opportunities.
- **Sensitivity Analysis:** A financial tool used to evaluate how changes in variables (e.g., costs) affect overall profitability or pricing.
- **Technical Assessment:** An evaluation of how well a product's technical features perform relative to competitors and internal benchmarks.
- **Technical Characteristics (HOWs):** Measurable engineering features designed to meet customer requirements as part of the HOQ framework.
- **Test Marketing:** The limited launch of a product to gauge market reactions and test marketing strategies before a full-scale rollout.
- **Total Acquisition Cost (TAC):** The complete set of costs associated with procuring and preparing a product for use, beyond the sticker price.
- **Total Life Cycle Cost (TLCC):** The full summation of all life cycle cost components, used to inform strategic pricing and investment decisions.
- **Total Ownership Cost (TOC):** The complete cost of owning a product, including acquisition, operation, maintenance, upgrades, training, and disposal.
- **Training Costs (TOC):** Expenses incurred to educate users or employees on proper operation and maintenance of the product.

OpenAI. (2025, May 23). ChatGPT. [Large language model]. <https://www.chatgpt.com>
 Prompt: *Provide a list of key terms, with definitions, for the following content.*

CHAPTER 5: PROCESS STRATEGY AND DESIGN

Chapter Overview

[5.0 Learning Outcomes](#)

[5.1 Process: Concept and Impact](#)

[5.2 Process Management](#)

[5.3 Managing Processes to Meet Demand](#)

[5.4 Decisions in Process Management & Process Choice](#)

[5.5 Vertical Integration](#)

[5.6 Resource Flexibility](#)

[5.7 Customer Involvement & Capital Intensity](#)

[5.8 Evaluation and Documentation of Processes](#)

[5.9 Chapter Summary & Review](#)

[5.10 Case Study: All Mats Services](#)

[5.11 Key Terms](#)

5.0 LEARNING OUTCOMES



Learning Outcomes

By the end of this chapter, students will be able to:

- Identify and describe the main categories of business processes.
- Analyze how process management helps organizations meet demand and manage process variability.
- Recognize the sources and types of process variation and their impact on business performance.
- Explain the five key decisions in process management: process choice, vertical integration, resource flexibility, customer involvement, and capital intensity.
- Distinguish between different process types (project, job shop, batch flow, line flow, and continuous flow).
- Apply process management concepts to real-world manufacturing and service operations.

5.1 PROCESS: CONCEPT AND IMPACT

As discussed in [Chapter Two](#), profit-oriented firms initiate the organization of their operations by establishing competitive priorities. These priorities typically include:

- Low-Cost Operations
- High-Performance Design
- Product Customization
- Development Speed
- Fast Delivery Time
- On-Time Delivery
- Volume Flexibility



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In practice, it is rarely feasible for a firm to outperform competitors across all these dimensions simultaneously. Most organizations strategically focus on excelling in one or two areas. The ability to achieve and sustain these competitive advantages is fundamentally dependent on the effectiveness of process management.

To better understand the significance of processes in business operations, it is useful to view them through the lens of operations chains. A **process** is defined as a structured set of activities that transforms inputs into outputs. The success of business operations is, therefore, intrinsically linked to how well these processes are designed, executed, and monitored.

Categorization of Business Processes

Organizations consist of numerous interdependent processes, which can be broadly categorized into three types:

- **Upper-Management Processes:** These govern the strategic direction and overall governance of the organization. Examples include corporate strategy formulation and organizational oversight.
- **Operational Processes:** These are the core value-generating activities of the business. They encompass functions such as procurement, production or service delivery, marketing, and sales.
- **Supporting Processes:** These provide essential support to the core operations. Examples include

finance and accounting, human resources, and information technology (IT).

Each business process, regardless of its scale, can be conceptualized as a sequence of supplier–customer relationships. Within this framework, every organizational unit, department, or individual function acts as both a customer of the preceding step and a supplier to the next. This interconnected structure ensures a continuous and coordinated flow of value across the organization.

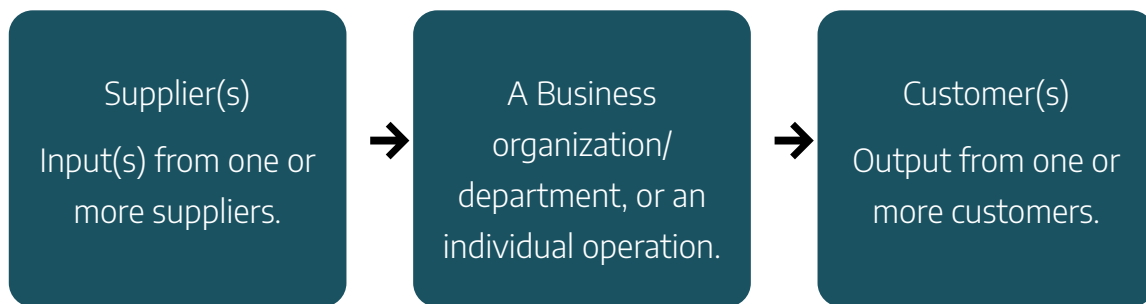


Figure 5.1.1: Business processes form a sequence of suppliers and customers.

Moreover, a major process often comprises multiple sub-processes, each with its own objectives that contribute to the overarching goals of the organization. Both individual firms and broader supply chains consist of numerous such processes and sub-processes. Adopting a process-oriented perspective enables organizations to optimize performance, enhance coordination, and drive continuous improvement.

This approach is formalized in Business Process Management (BPM), which encompasses three key activities:

- *Process Design*: Structuring processes to align with strategic goals.
- *Process Execution*: Implementing processes efficiently and effectively.
- *Process Monitoring*: Continuously evaluating performance to identify areas for improvement.

In the context of operations and supply chain management, two critical aspects of BPM are:

- Managing processes to meet demand
- Addressing process variability

These dimensions are essential for maintaining operational efficiency, responsiveness, and long-term competitiveness.

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5.2 PROCESS MANAGEMENT

Process management refers to the systematic planning, execution, and monitoring of business processes to ensure they operate efficiently and effectively. A **business process** is a structured network of interrelated activities that utilize available resources to transform inputs into valuable outputs.

At its core, process management involves the application of managerial principles and practices aimed at optimizing process performance over time. The ultimate goal is to align process outcomes with the strategic objectives of the organization, thereby enhancing overall effectiveness and profitability.

Process management typically encompasses both business processes (such as customer service, procurement, and logistics) and manufacturing processes (such as production and quality control).

It involves a comprehensive set of activities, including:

- *Defining* the process structure and objectives
- *Visualizing* workflows and interdependencies
- *Measuring* performance using relevant metrics
- *Controlling* process execution to ensure consistency
- *Reporting* outcomes for transparency and accountability
- *Improving* processes through continuous refinement and innovation

To meet evolving customer requirements and maintain a competitive advantage, organizations must leverage a combination of *knowledge, skills, tools, techniques, and systems*. These elements form the foundation of effective process management and enable organizations to deliver value in a sustainable and profitable manner.

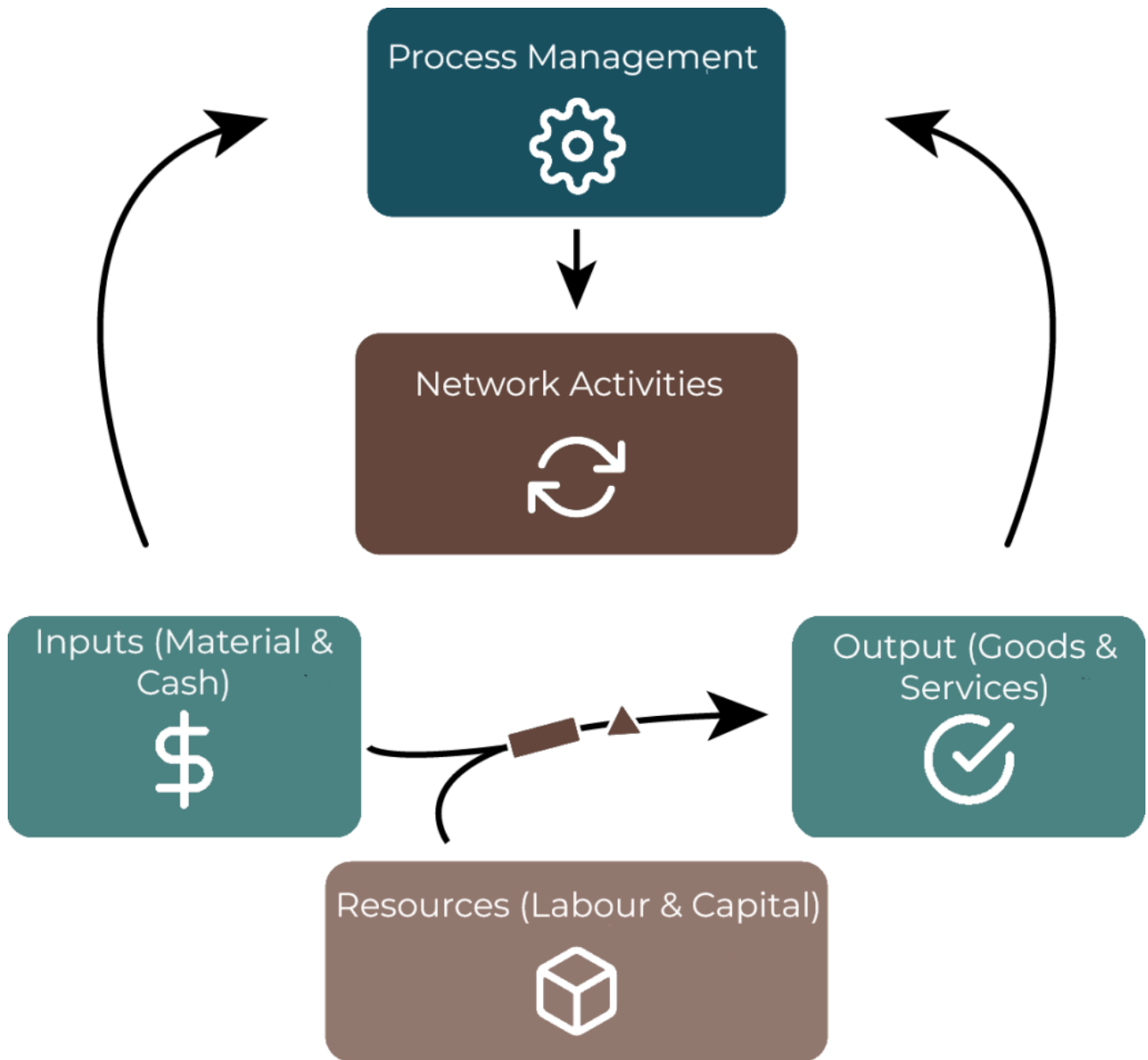


Figure 5.2.1: Business processes form a sequence of suppliers and customers. “[A Process Management Perspective](#)” by Suhanshu Joshi, [CC BY-NC 4.0](#). Mods: Redesigned.

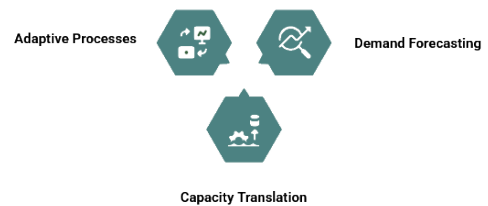
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5.3 MANAGING PROCESSES TO MEET DEMAND

An essential objective of process management is to align process capacity with customer demand. Ideally, a process should be designed so that its output precisely matches demand levels. Excess capacity leads to inefficiencies and increased operational costs, while insufficient capacity results in unmet customer needs, lost revenue, and potential damage to the organization's reputation.

Achieving this balance requires:

- Accurate demand forecasting
- Translation of forecasts into capacity requirements
- Processes capable of adapting to expected demand levels



However, even with robust planning, process variation and demand variability can make it challenging to maintain this alignment. Therefore, effective process management must also include strategies for managing and mitigating variation.

Image generated with [Napkin AI](#), [Napkin Licence](#)

Process Variation

Variation is an inherent characteristic of all business processes. It can arise from both intentional choices (e.g., offering a wide range of products) and uncontrollable factors (e.g., random fluctuations in demand).

Understanding the sources of variation is critical for designing resilient and responsive operations.

There are four primary sources of variation:

1

Variety of Goods or Services Offered. The broader the range of products or services, the more complex and variable the production or service delivery requirements become.

2

Structural Variation in Demand. These include predictable patterns such as seasonality, trends, and cyclical fluctuations. While they can be anticipated, they still require proactive capacity planning and resource allocation.

3

Random Variation. This type of variation is inherent in all processes and demand patterns. It is unpredictable and cannot be eliminated, though its impact can be mitigated through statistical analysis and buffer strategies.

4

Assignable Variation: These variations stem from identifiable causes such as defective inputs, inefficient work methods, or malfunctioning equipment. Unlike random variation, assignable variation can often be reduced or eliminated through root cause analysis and corrective action.

The Impact of Variation

Process variation can significantly disrupt operations and supply chains. Its consequences include:

- Increased operational costs
- Delays and inventory shortages
- Reduced product or service quality
- Inefficient workflows
- Customer dissatisfaction and reputational damage

Given these risks, the ability to identify, analyze, and manage variation is a critical competency for operations and supply chain managers. Effective variation management not only enhances process stability but also supports strategic goals such as customer satisfaction, cost efficiency, and continuous improvement.

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5.4 DECISIONS IN PROCESS MANAGEMENT & PROCESS CHOICE

Effective process management hinges on five key decisions that are critical to an organization's success:

1. *Process Choice*: Selecting the most appropriate process type.
2. *Vertical Integration*: Determining the extent to which a firm performs activities in-house.
3. *Resource Flexibility*: Deciding on the adaptability of labour, equipment, and facilities.
4. *Customer Involvement*: Defining the degree to which customers participate in the process.
5. *Capital Intensity*: The level of investment in equipment versus labour.

A thorough understanding of these decisions, along with associated terminology such as *Project Process*, *Job Shop Process*, *Batch Flow Process*, *Line Flow Process*, and *Continuous Flow Process*, is essential and will be further explored in the subsequent sections.

Process Choice

The first and most fundamental decision in process management is process choice—selecting the appropriate process structure to support the organization's strategic objectives. To make an informed choice, it is important to understand the characteristics of different process structures, often referred to as process architecture or process structure.

Key attributes that differentiate process structures include:

- a. *Flow*: The degree of sequencing in activities, ranging from highly flexible paths to a single, fixed sequence.
- b. *Flexibility*: The extent to which a process can adapt to changes in volume or product mix without significant cost or performance degradation.
- c. *Number of Products*: The range of different products or services the process can handle, from highly customized to standardized.
- d. *Capital Investment*: The level of investment in equipment, from general-purpose, low-cost tools to highly specialized, capital-intensive machinery.
- e. *Variable Cost*: The cost per unit of output, which typically decreases as processes become more standardized and automated.
- f. *Labour Content and Skill*: The amount and complexity of human labour required, ranging from high-skill, labour-intensive processes to low-skill, automated systems.
- g. *Volume*: The scale of production, from one-off or small-batch production to high-volume mass production.

These attributes tend to vary monotonically across the spectrum of process types—from highly flexible, low-volume processes to highly standardized, high-volume ones.

Types of Process Structures

The main types of process structures used in manufacturing and service operations include:

- a. **Project Process:** Used for unique, one-of-a-kind outputs such as construction projects or custom software development. High flexibility, low volume.
- b. **Job Shop:** Suitable for low-volume, high-variety production. Examples include custom furniture or specialized machine parts.
- c. **Batch Flow:** Involves producing moderate volumes of similar items in groups or batches. Common in bakeries or clothing manufacturing.
- d. **Line Flow:** Characterized by a standardized sequence of operations, suitable for high-volume production with limited variety (e.g., automobile assembly lines).
- e. **Continuous Flow:** Used for very high-volume, standardized production with minimal variation, such as in oil refining or chemical manufacturing.

The characteristics of the above processes are examined in the following sections.

Project Process

A project process represents the high-customization, low-volume end of the process continuum. It is typically used for unique, large-scale, and complex undertakings such as constructing a hospital, developing a new technology, or organizing a major event. Each project is distinct, with a specific set of objectives, a defined timeline, and a unique sequence of operations. Key characteristics include:

- High customization and low repetition
- Flexible workflows that are redefined for each project
- Resource-intensive at specific stages, with fluctuating demand for labour and equipment

- Coordination-intensive, requiring close integration of interdependent tasks

Organizations employing project processes often compete based on their capabilities rather than standardized offerings. Success depends on effective project management, resource allocation, and the ability to adapt to evolving client requirements.

Job Shop Process

A job shop process is designed for producing small batches of a wide variety of custom or semi-custom products. It is characterized by high flexibility and low production volume. Examples include machine shops, custom furniture makers, and specialized repair services. Key features:

- General-purpose equipment grouped by function (e.g., lathes, drills, milling machines)
- Highly skilled labour capable of handling diverse tasks
- Flexible routing, where each job may follow a different path through the facility
- Low efficiency, but high adaptability to customer-specific requirements

Job shops are ideal for environments where *product variety is high and demand for each product is low*. They rely heavily on the expertise of workers and the ability to reconfigure workflows dynamically.

Batch Flow Process

A batch flow process bridges the gap between job shops and line flow systems. It is used to produce moderate volumes of similar products in groups or batches. While it retains some flexibility, it introduces more structure and repeatability. Key characteristics:

- Dominant flow patterns, though not fully continuous
- Moderate customization with higher volumes than job shops
- Setup times required between batches, impacting efficiency

- Common applications include bakeries, pharmaceuticals, and paint manufacturing

Batch processes allow for a balanced trade-off between flexibility and efficiency, making them suitable for organizations that produce a variety of products in recurring quantities.

Line Flow Process

A line flow process is used for high-volume production of standardized products. It features a fixed sequence of operations, with materials moving linearly from one workstation to the next. Key attributes:

- Standardized products with minimal variation
- High efficiency due to repetitive tasks and streamlined flow
- Low work-in-process inventory, as items move continuously
- Examples include automobile assembly lines, electronics manufacturing, and fast-food services

Line flow processes typically follow a make-to-stock strategy, producing goods in anticipation of customer demand. While product variety is limited, it can be introduced through modular design or standardized options.

Continuous Flow Process

A continuous flow process represents the extreme end of the process continuum, characterized by uninterrupted production of a single, standardized product. It is commonly used in industries such as oil refining, chemical production, and electricity generation. Key features:

- Fixed sequence and constant pace of operations
- Highly capital-intensive, with minimal direct labour
- Low variable costs due to economies of scale

- Output measured in volume or weight (e.g., litres, tons)

This process type is ideal for the mass production of homogeneous products. While it offers minimal flexibility, it delivers maximum efficiency and cost-effectiveness at scale.

Table 5.4.1. Characteristics of Different Types of Processes

Process Type	Volume	Flexibility	Custom-ization	Capital Intensity	Variable Cost	Labour Content	Flow Structure
Project Process	Low	Very High	High	Low	High	High	Flexible
Job Shop Process	Low	High	High	Moderate	High	High	Flexible
Batch Flow Process	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Dominant
Line Flow Process	High	Low	Low	High	Low	Low	Fixed
Continuous Flow Process	Very High	Very Low	Very Low	Very High	Very Low	Very Low	Fixed

Watch this video on Process Selection:

Video: “[Process Selection – A Review of Continuous Flow, Assembly Line, Batch Flow and Job Shop](#)” by [Dr. Haywood](#) [7:29] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

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5.5 VERTICAL INTEGRATION

Vertical integration is a strategic decision that plays a critical role in shaping corporate strategy. It refers to a firm's efforts to gain control over multiple stages of its industry's value chain—either upstream (toward suppliers) or downstream (toward customers). The primary objectives of vertical integration include:

- Enhancing market power
- Reducing transaction and coordination costs
- Securing reliable access to inputs or distribution channels
- Improving product quality and delivery performance

All firms rely on external sources for at least some of their inputs—whether raw materials, components, or services. The **degree of vertical integration** reflects how many of these activities a firm chooses to perform internally rather than outsourcing. This decision is often framed as a “*make or buy*” choice:

- *Make*: Perform the activity in-house (greater integration)
- *Buy*: Outsource the activity to external suppliers (less integration)

Once these decisions are made, firms must develop systems to coordinate and integrate internal processes with those of external partners to ensure seamless operations.

Types of Vertical Integration

Vertical integration can take three primary forms:

Backward Integration (Upstream Integration)

This involves acquiring or controlling sources of supply. For example, an automobile manufacturer might own a tire company or a steel plant. The goal is to ensure a stable supply of inputs, reduce dependency on suppliers, and maintain consistent quality. Historically, companies like Ford Motor Company used this strategy extensively to control their entire supply chain.

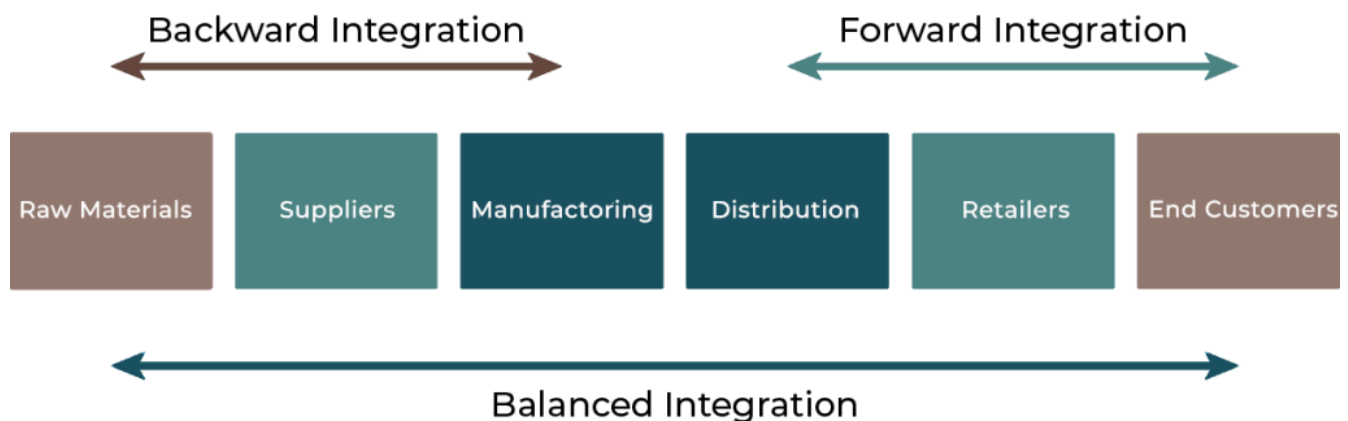
Forward Integration (Downstream Integration)

This strategy involves gaining control over distribution channels or retail outlets. For instance, a manufacturer might acquire a chain of retail stores to sell its products directly to consumers. This allows the firm to capture more value, improve customer experience, and respond more quickly to market changes.

Balanced Integration

Balanced integration combines both backward and forward integration. Firms adopting this approach aim to control both input sourcing and product distribution, thereby maximizing control over the entire value chain.

Types of Vertical Integration within a Supply Chain



Backward Integration (●): Control moves upstream toward raw materials and suppliers.
Forward Integration (●): Control moves downstream toward distribution and retail.
Balanced Integration (●): Combines both backward and forward integration, spanning the entire value chain.

Figure 5.5.1. “Types of Vertical Integration” by Koen Liddiard, [CC BY-NC-SA 4.0](#). Inspired by an AI diagram from the prompt “Create a visual diagram illustrating three types of vertical integration within a supply chain” and an [image](#) by Abby Jenkins.

Image Description

A diagram titled “Types of Vertical Integration within a Supply Chain” showing a horizontal flow from “Raw Materials” to “End Customers” through the stages: Raw Materials, Suppliers, Manufacturing, Distribution, Retailers, and End Customers.

- Backward Integration is illustrated with a double-headed arrow pointing leftward from Manufacturing toward Raw Materials, indicating control moving upstream.
- Forward Integration is shown with a double-headed arrow pointing rightward from Manufacturing toward End Customers, indicating control moving downstream.
- Balanced Integration is represented by a long arrow spanning both directions across the entire chain from Raw Materials to End Customers.

Below the diagram, definitions are provided:

- Backward Integration: Control moves upstream toward raw materials and suppliers.
- Forward Integration: Control moves downstream toward distribution and retail.
- Balanced Integration: Combines both backward and forward integration, spanning the entire value chain.

Advantages and Disadvantages of Vertical Integration

Advantages	Disadvantages
Increases market share and competitive advantage	Higher operational complexity and management burden
Facilitates entry into foreign or new markets	Risk of inefficiency if the firm lacks expertise in new activities
Enhances product quality and consistency	Reduced flexibility due to fixed internal supply or distribution structures
Improves delivery reliability and responsiveness	Potential for lower innovation due to reduced external competition
Reduces transaction costs and dependency on external suppliers or distributors	Capital-intensive and may require significant upfront investment

“[4. Process Management: Types of Process and its Implication in Operation Strategy](#)” from [Operations](#)

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5.6 RESOURCE FLEXIBILITY

Resource flexibility refers to the ability of an organization's resources (workforce, facilities, and equipment) to adapt to changing operational requirements. The degree of flexibility required is determined by the firm's competitive priorities, such as product customization, responsiveness, and cost efficiency.

For instance, when a firm competes on product customization or operates in markets with short product life cycles, it must rely on a flexible workforce capable of performing a wide range of tasks and on general-purpose equipment that can be quickly reconfigured. Conversely, when the focus is on cost efficiency and high-volume production, specialization and dedicated equipment may be more appropriate.



Primary Dimensions of Resource Flexibility

Two primary dimensions of resource flexibility are:

Workforce Flexibility

Operations managers must decide whether to employ a flexible workforce —employees who are cross-trained to perform multiple tasks across different workstations or not.

This flexibility enhances responsiveness and adaptability, but comes at a cost:

- *Advantages:* Greater adaptability to product variety and volume fluctuations
- *Challenges:* Requires significant investment in training and development; may lead to higher labour costs

The choice of workforce structure also depends on volume variability:

- *Stable demand:* A permanent, full-time workforce is typically preferred
- *Fluctuating demand:* A mix of part-time, temporary, or contract workers may be more cost-effective

Equipment Flexibility

The selection of equipment depends on the product mix, volume, and customization level:

- *Low volume, high customization:* Requires general-purpose equipment that is flexible and relatively inexpensive, with low fixed costs and high variable costs.
- *High volume, low customization:* Justifies investment in specialized equipment with high fixed costs but low variable costs, leading to economies of scale.

Types of Flexibility

- *Product Flexibility:* The ability to produce a wide range of products or services

- *Volume Flexibility*: The ability to operate efficiently across a wide range of output levels

For example, a 24-hour fast-food restaurant demonstrates volume flexibility by adjusting staffing and operations to match demand fluctuations throughout the day.

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5.7 CUSTOMER INVOLVEMENT & CAPITAL INTENSITY

Customer Involvement

Customer involvement refers to the degree to which customers participate in or influence the execution of a process. It is a critical dimension of process design, particularly in service operations, and can significantly affect cost, quality, customization, and delivery performance.

The extent, nature, and form of customer involvement can vary widely depending on the industry, product or service type, and competitive priorities. Below are key forms of customer involvement:

Self-Service

In self-service models, customers perform tasks traditionally handled by the provider. This approach is common in retail environments where cost leadership is a strategic priority. Examples include:

- Self-checkout kiosks in supermarkets
- Online banking and ticket booking
- Assembly-required products such as furniture, toys, or bicycles

Self-service reduces labour and operational costs for the firm, which can be passed on to customers in the form of lower prices. It also empowers customers with greater control and convenience.

Product Selection and Customization

In businesses that compete on **customization**, customers may be actively involved in specifying or even designing the product or service. This form of involvement is particularly prevalent in:

- Custom-built homes
- Tailored clothing
- Personalized software solutions

Here, the customer's role extends beyond consumption to co-creation, influencing both the design and

production phases. This high level of involvement enhances satisfaction but requires flexible processes and close communication.

Time and Location Determination

In many service settings, the **time and location** of service delivery are dictated by the customer. This introduces additional complexity into process design. Key considerations include:

- Will the service be delivered on the provider's premises, at the customer's location, or at a third-party site?
- Is the service scheduled by appointment, or is it on demand?
- How will the process accommodate variability in customer availability and preferences?

Examples include home healthcare services, on-site equipment repair, and mobile car detailing. These scenarios require flexible scheduling systems and mobile resources.

Strategic Implications

The level of customer involvement has significant implications for:

- *Process efficiency*: Higher involvement may reduce provider workload but increase variability
- *Cost structure*: Self-service can lower costs, while customization may increase them
- *Customer experience*: Involvement can enhance satisfaction and perceived value
- *Process design*: Requires adaptable workflows, communication systems, and sometimes co-location of resources

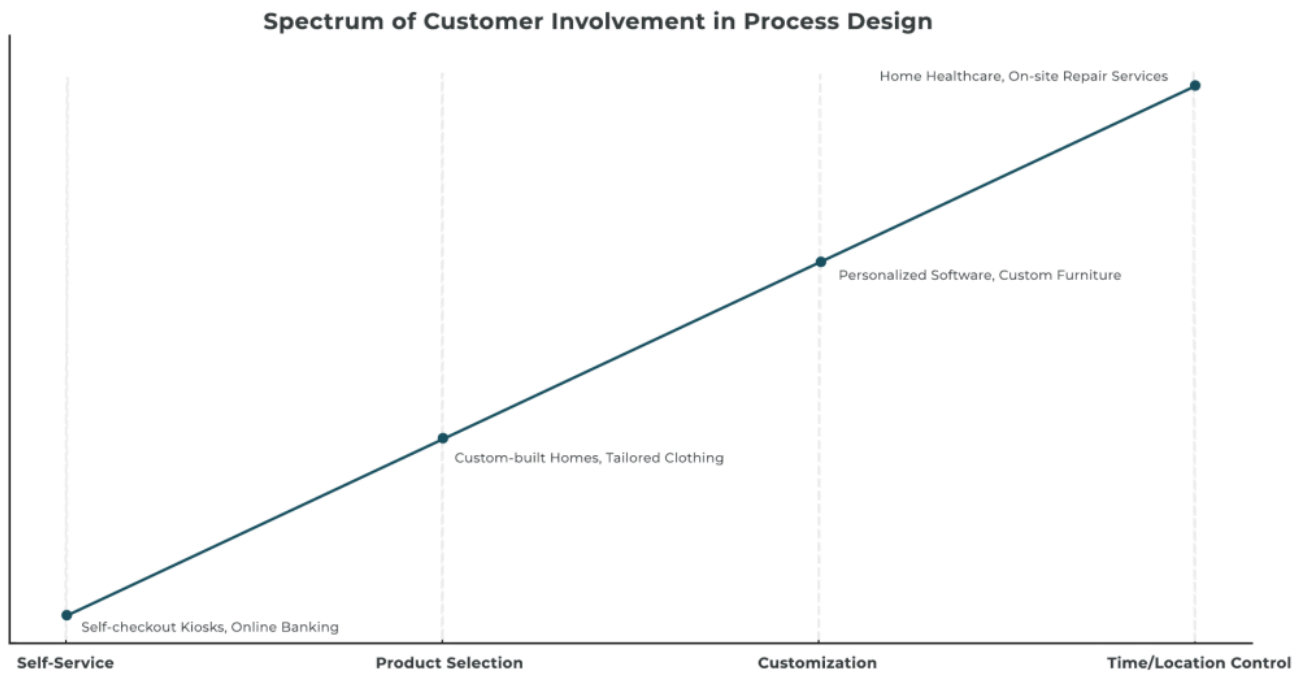


Figure 5.7.1. “Spectrum of Customer Involvement in Process Design” by ChatGPT, prompt: Create a visual diagram illustrating the spectrum of customer involvement in process design; edited.

Capital Intensity

Capital intensity refers to the extent to which a production process relies on equipment and technology relative to human labour. A process is considered capital-intensive when a significant portion of its cost structure is attributed to machinery, automation, and infrastructure rather than workforce expenses.

As technological capabilities continue to advance and costs decline, operations managers are presented with a broader spectrum of choices—from manual, labour-intensive systems to highly automated, capital-intensive operations. The selection of capital intensity must align with the organization’s competitive priorities, such as cost efficiency, flexibility, quality, and responsiveness.

Types of Automation

Automation plays a central role in capital-intensive operations. It refers to systems, equipment, or processes that operate with minimal human intervention. There are two primary types of automation:

Fixed Automation (Hard Automation)

- Designed for high-volume, repetitive tasks

- Utilizes special-purpose equipment to perform a fixed sequence of operations
- Common in assembly lines and mass production environments
- Offers high efficiency but low flexibility

Flexible Automation (Soft Automation)

- Capable of adapting to different product configurations
- Uses programmable equipment that can change the sequence of operations
- Suitable for moderate-volume, high-variety production
- Balances efficiency and adaptability

Strategic Considerations

While automation and capital intensity can offer significant advantages, they also come with trade-offs. Key considerations include:

Advantages	Disadvantages
Increases productivity and throughput	High initial investment and maintenance costs
Enhances product consistency and quality	It may not be cost-effective for low-volume or highly customized operations
Reduces reliance on manual labour and human error	Can reduce workforce flexibility and adaptability
Supports scalability and long-term cost reduction	May conflict with competitive priorities focused on personalization or service

Importantly, *capital intensity is not always the optimal choice*. For firms that compete on *customization, service quality, or personal attention*, a more labour-intensive approach may better align with strategic goals. In such cases, skilled human resources may deliver greater value than automation.

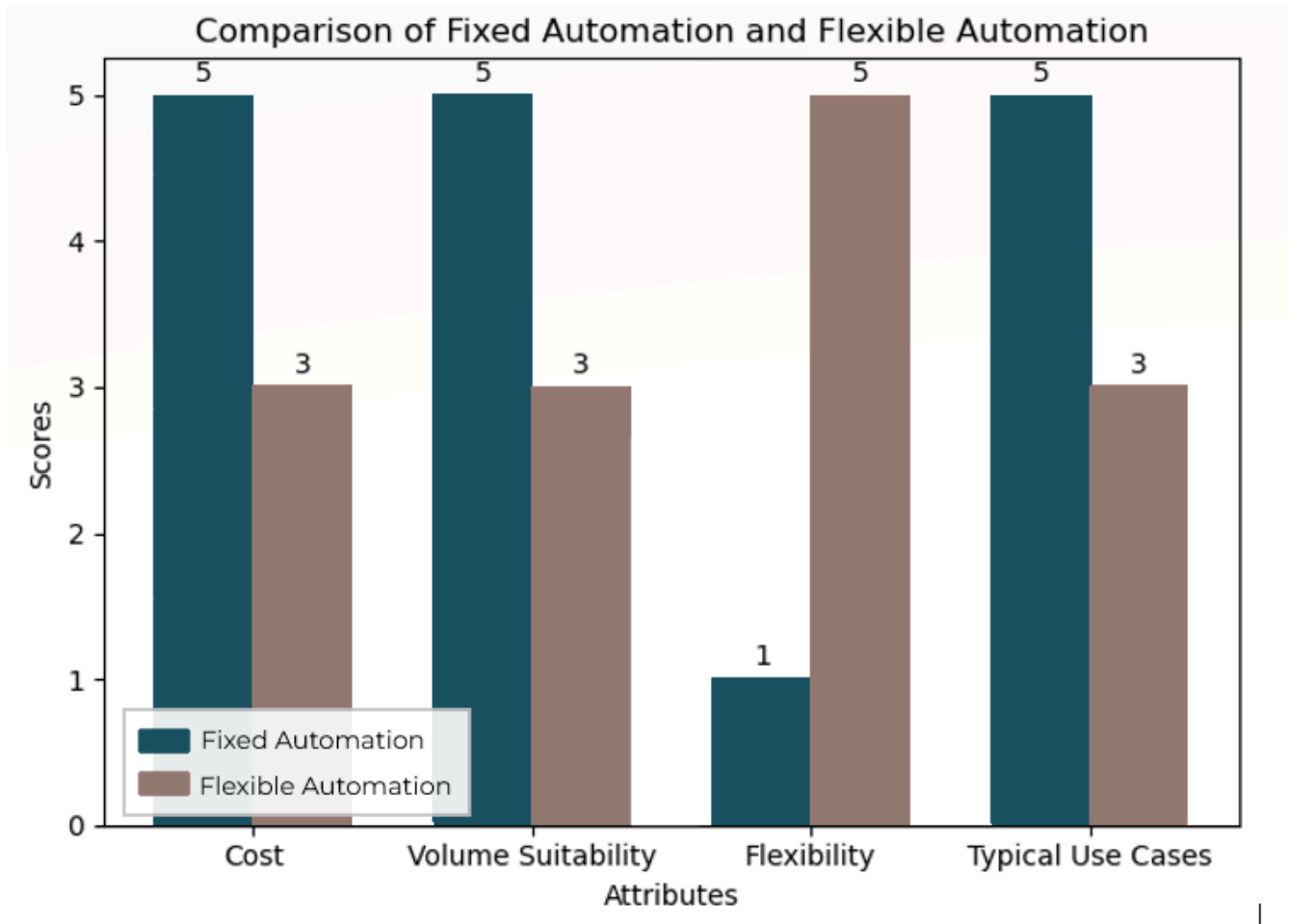


Figure 5.7.2. “Comparison of Fixed vs Flexible Automation” by ChatGPT Prompt: Create a visual diagram comparing Fixed Automation and Flexible Automation across key dimensions.

Figure Explanation:

- *Cost*: Fixed automation typically involves a higher upfront investment due to specialized equipment.
- *Volume Suitability*: Fixed automation is ideal for high-volume, repetitive tasks; flexible automation suits moderate volumes.
- *Flexibility*: Flexible automation excels in adaptability, making it suitable for varied product configurations.
- *Typical Use Cases*: Fixed automation is used in mass production (e.g., automotive assembly), while flexible automation is common in environments requiring frequent changeovers (e.g., electronics or custom manufacturing)

Video: “[Process Strategy Decisions](#)” by [DrAnand](#) [10:21] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

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5.8 EVALUATION AND DOCUMENTATION OF PROCESSES

The evaluation and documentation of business processes are essential for understanding, optimizing, and managing organizational workflows. These practices provide a structured approach to visualizing how work is performed, identifying inefficiencies, and implementing improvements that enhance performance, reduce errors, and optimize resource utilization.

The Importance of Process Documentation

Effective process documentation serves several strategic and operational purposes. Key benefits include:

Standardization

Ensures consistency in task execution across departments and teams, reducing variability and enhancing quality.

Training and Onboarding

Acts as a reference guide for new employees and supports cross-training initiatives, accelerating learning and reducing dependency on informal knowledge transfer.

Regulatory Compliance

Helps organizations meet external regulatory requirements and internal quality standards by providing clear, auditable records of how processes are executed.

Continuous Improvement

Facilitates the identification of bottlenecks, redundancies, and inefficiencies, enabling data-driven process enhancements.

Knowledge Retention

Captures institutional knowledge, preserving critical information and reducing reliance on specific individuals or informal practices.

Common Tools for Process Documentation

To effectively document and evaluate processes, organizations use a variety of tools. Two of the most widely adopted are:

- **Process Flow Diagrams:** Visual representations that map out the sequence of activities, decisions, and flows within a process. They help stakeholders quickly understand how a process operates from start to finish.
- **Process Charts:** Tabular or graphical tools that detail the steps in a process, including the type of activity (e.g., operation, inspection, transport), the resources involved, and the time or cost associated with each step.

These tools will be explored in greater detail in the following sections, providing practical guidance on how to apply them in real-world business contexts.

Symbol	Name	Function
	<i>Parallelogram</i>	Used to represent Input or output
	<i>Rectangle</i>	Used to Represent a process or an activity
	<i>Oval</i>	Represents a start or end point
	<i>Arrow</i>	A connector line used to display movements/relationship
	<i>Diamond</i>	Used to show that a decision is made
	<i>Circle (Connector)</i>	Shows inspection point within flow across sections of the chart
	<i>D Delay</i>	Used to represent a pause or delay in the process
	<i>Triangle</i>	Represents inventory or queue

Figure 5.8.1. “Elements of Process Flow Diagram” by Koen Liddiard, [CC BY-NC-SA 4.0](https://creativecommons.org/licenses/by-nc-sa/4.0/) (Six Sigma, n.d.).

Image Description

A table showing common flowchart symbols, their names, and their functions. It has three columns labelled “Symbol,” “Name,” and “Function.” The rows are as follows:

- Parallelogram – Used to represent input or output.
- Rectangle – Used to represent a process or an activity.
- Oval – Represents a start or end point.
- Arrow – A connector line used to display movements/relationships.
- Diamond – Used to show that a decision is made.
- Circle (Connector) – Shows inspection point within the flow across sections of the chart.
- D Delay – Used to represent a pause or delay in the process.
- Triangle – Represents inventory or queue.

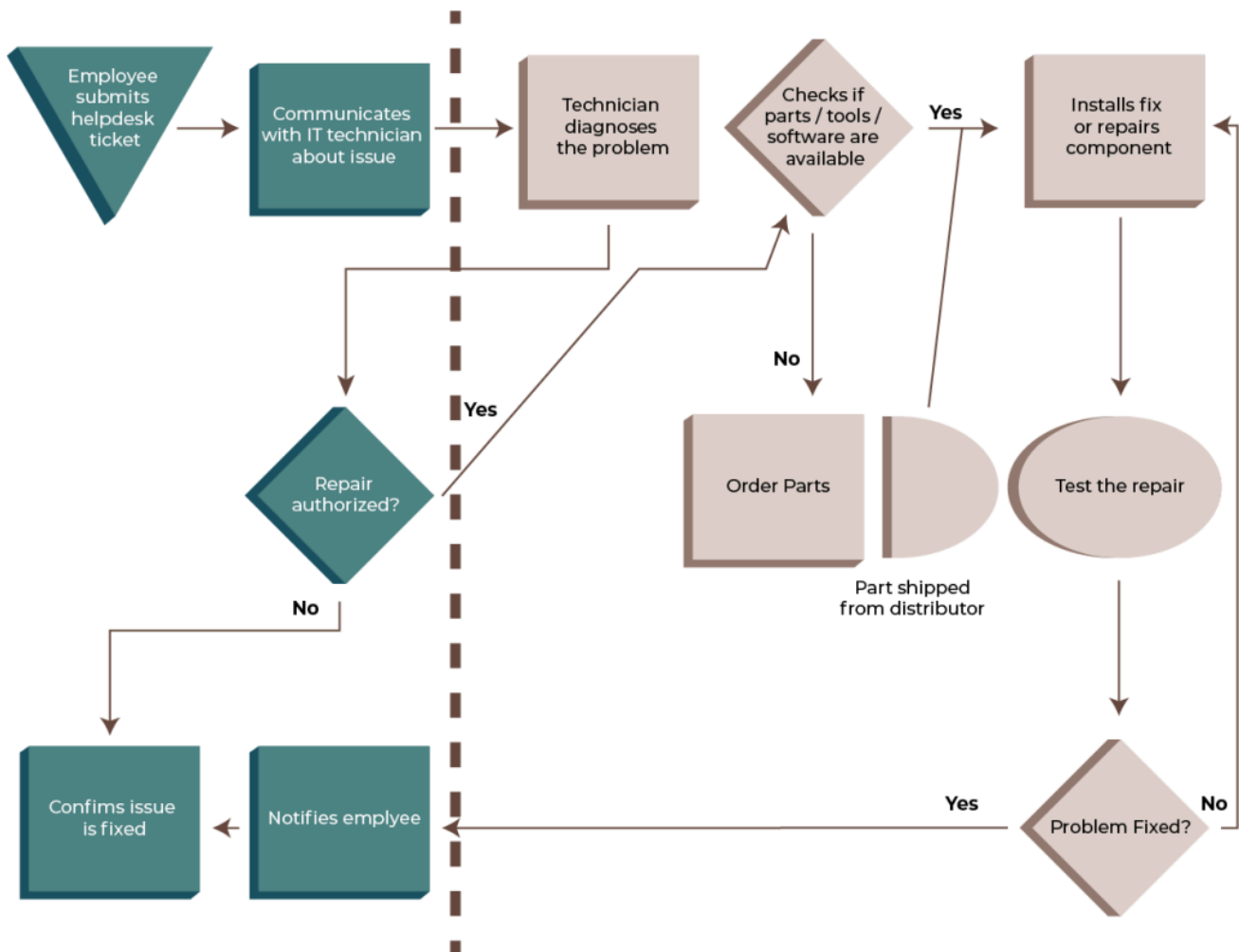


Figure 5.8.2. “IT Ticket Process Flow Diagram” created by ChatGPT, prompt: What is something similar to the process of auto repair in a service garage in Operations Management?; edited.

Image Description

A flowchart illustrating the IT helpdesk ticket process. It is divided into two sections by a dashed vertical line.

The left section represents the employee and initial communication; the right section represents technician actions and repair processes.

Left section (Employee/Communication):

- Triangle: “Employee submits helpdesk ticket”
- Rectangle: “Communicates with IT technician about issue”
- Diamond: “Repair authorized?”
- If No → “Notifies employee” → “Confirms issue is fixed”
- If Yes → Flows to technician side

Right section (Technician):

- Rectangle: “Technician diagnoses the problem”
- Diamond: “Checks if parts/tools/software are available”
- If Yes → “Installs fix or repairs component”
- If No → “Order Parts” → Half-circle: “Part shipped from distributor”
- Oval: “Test the repair”
- Diamond: “Problem fixed?”
- If Yes → Return to employee side: “Notifies employee” → “Confirms issue is fixed”
- If No → Loops back to diagnosis or additional repair steps

The chart uses standard flowchart shapes and directional arrows to indicate decision paths and sequences. Color coding distinguishes employee-related steps (teal) from technician-related steps (brown).

A process flow diagram can go beyond representing the production process by showing all the activities that are carried out in an organization. These diagrams are known as Swim Lane flows, as shown in Figure 5.6.3, depicting the process of order filling.

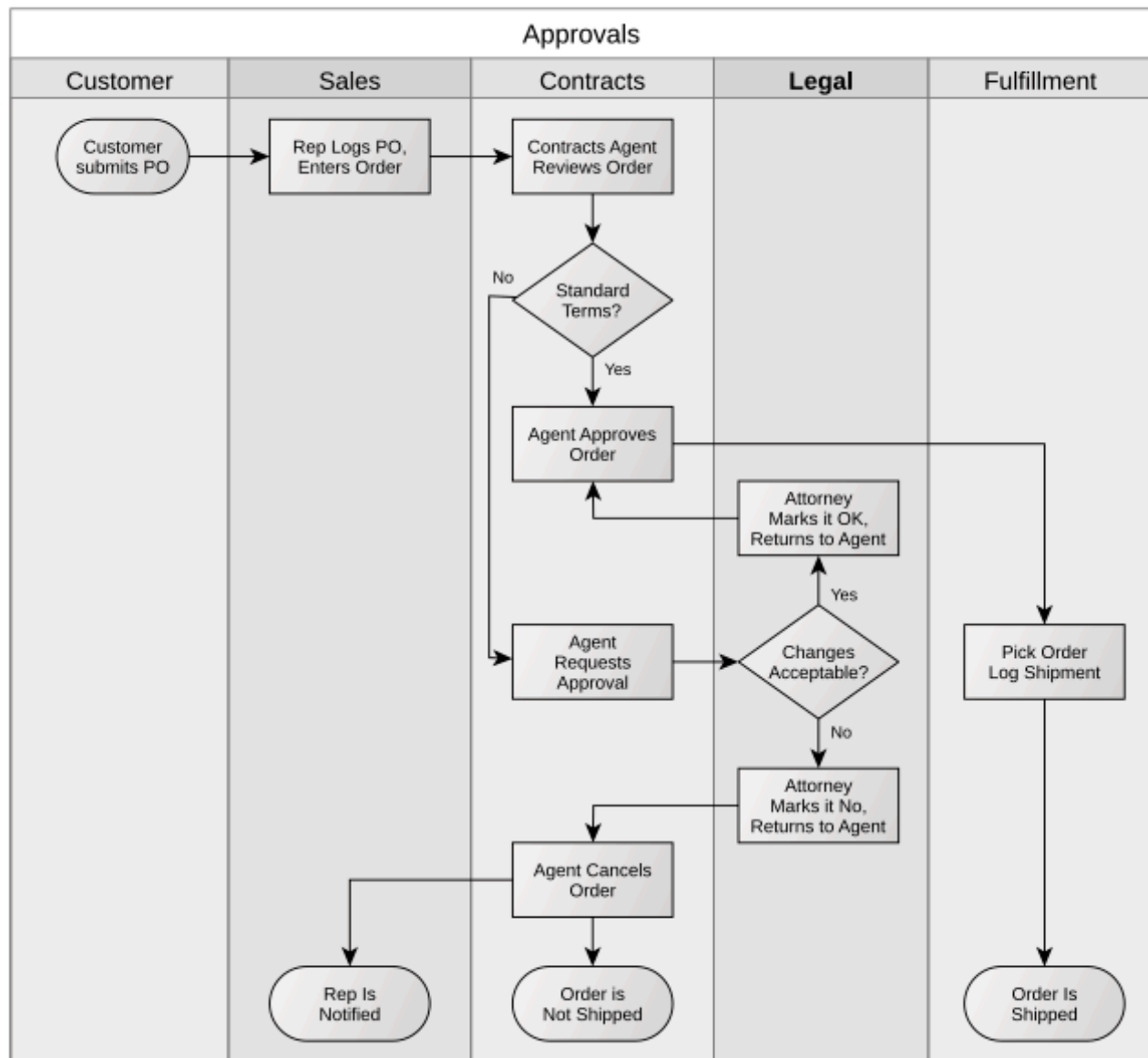


Figure 5.8.3. "Example of Swim Lane Flowchart" by Paul Kerr, [CC0](#).

Image Description

A swimlane flowchart titled "Approvals" depicts the order approval process across five departments: Customer, Sales, Contracts, Legal, and Fulfillment.

- In the Customer lane: A process starts with "Customer submits PO" (purchase order).
- In the Sales lane: "Rep Logs PO, Enters Order."
- In the Contracts lane:
 - "Contracts Agent Reviews Order"
 - Decision: "Standard Terms?"

- If Yes → “Agent Approves Order” → Moves to Fulfillment.
- If No → “Agent Requests Approval”
- If denied → “Agent Cancels Order” → “Rep is Notified” (Sales) → “Order is Not Shipped”
- If legal review is needed, it moves to the Legal lane.
- In the Legal lane:
 - “Attorney Marks it OK, Returns to Agent”
 - Or decision: “Changes Acceptable?”
 - If Yes → “Attorney Marks it OK, Returns to Agent”
 - If No → “Attorney Marks it No, Returns to Agent”
- If approved by Legal and Contracts, it goes to the Fulfillment lane:
 - “Pick Order, Log Shipment” → “Order is Shipped.”

The flowchart uses standard symbols: ovals for start/end, rectangles for processes, and diamonds for decisions. Each lane represents a department, and the flow of tasks is shown using arrows.

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

5.9 CHAPTER SUMMARY & REVIEW



Summary

This chapter focuses on process strategy and design, emphasizing how organizations manage and structure their operations to achieve competitive priorities such as cost efficiency, flexibility, quality, and speed. It introduces the concept of business process management (BPM), which involves process design, execution, and monitoring to align capacity with demand and address process variation. Processes are categorized into three types: upper-management (strategic direction), operational (core value creation), and supporting (finance, HR, IT). Variation, whether structural, random, or assignable, poses challenges that can disrupt operations, making effective management essential for stability, efficiency, and customer satisfaction.

A key part of process strategy involves making five major decisions: process choice, vertical integration, resource flexibility, customer involvement, and capital intensity. The chapter outlines five process structures: project, job shop, batch flow, line flow, and continuous flow. Each is suited to different volumes, customization levels, and capital investments. It also examines vertical integration (backward, forward, and balanced), along with its advantages and risks, and explores the strategic role of resource flexibility and customer involvement in shaping processes. Finally, the chapter stresses the importance of capital intensity and automation choices, as well as process documentation tools like flow diagrams and process charts, which support standardization, training, compliance, and continuous improvement. Collectively, these concepts provide a framework for designing efficient, adaptable, and strategically aligned processes.

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Review Questions

1. Define process management and explain its importance in business operations.
2. List and describe the three main categories of business processes with examples.
3. What are the key activities involved in business process management (BPM)?¹
4. Explain how process management helps organizations meet demand and manage variability.
5. Identify and discuss the four basic sources of process variation. Provide examples for each.
6. How does process variation impact business operations and customer satisfaction?¹
7. What are the five key decisions in process management? Briefly explain each.
8. Compare and contrast process choice and vertical integration in process management.
9. Describe the characteristics of a project process and give an example from the service sector.
10. How does a job shop process differ from a batch flow process? Provide examples.
11. Explain the main features of a line flow process and identify industries where it is commonly used.
12. What are the advantages and disadvantages of a continuous flow process?
13. Discuss how resource flexibility and customer involvement influence process design decisions.
14. Using the provided table, compare the five process types in terms of flow, flexibility, capital investment, and labour skill.
15. Why is it challenging for an operation to excel in more than one or two competitive priorities? Illustrate with examples.
16. How can process management contribute to achieving low-cost operations and high-performance design?¹
17. Describe the role of supporting processes in an organization. Why are they

essential?

18. What is the relationship between process structure and process performance?
19. Discuss the impact of process management on supply chain efficiency.
20. Provide a real-world example of a business that successfully uses process management to gain a competitive advantage. Explain how.

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create some discussion questions based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

5.10 CASE STUDY: ALL MATS SERVICES



Case Study: All Mats Services

All Mats Services is a sizable family-owned workshop in Mississauga that offers cleaning and repair services for factories, garages, hospitals, retailers and offices in GTA and beyond. The shop was founded and is owned by Ali Karami, who started this business in 1975 by going to repair shops, collecting their door mats to wash them in his small pick-up truck. In nearly two decades, he expanded his operation to what it is today. Crucial to his business success was his keen attention to fine detailing and rejuvenating old mats, which brought him a sound reputation among the clients he served.

The bulk of All Mats orders come for cleaning rubber-based mats and runners. Equipped with the latest cleaning machinery, the workshop operates 8 hours a day, five days a week (Monday-Friday) throughout the year. Rooted in Ali's reputation with refurbishing plush products (door mat, runners, area mats/rugs), the shop also accepts cleaning orders of these products.

Although Ali is satisfied with his operational revenue, he sometimes gets upset about the backlog of orders that could negatively impact the efficient and timely delivery of the finished jobs to some clients. As an expediting measure, the shop receives the orders in a rolled bundle tagged for each client and delivers the finished jobs in the same manner and using the same tags. In an attempt to manage efficient and timely delivery and improve his operation, Ali has hired your group as consultants to examine the All Mats operations and offer recommended solutions. Last Monday, your group held a meeting in his office where he provided the following operational details.

"I am very obsessed with clean delivery of finished jobs, so all jobs come into the shop floor in our trucks, bundled and tagged by order number and client's name and when

finished, shipped out in our own trucks.” Ali continued, “Upon arrival, bundles are inspected by our receivers to make sure they are all good. On average, this is done in about 5 minutes. After that, jobs would be divided into two categories: a) Rubber and b) Plush. All rubber jobs will go through three processes: scraping, washing and dry/shine. Now let’s walk through the shop and see them done in action,” said Ali. During your tour of rubber operations, you noted that in the “scraping” stage, mats and runners were guided through scraper rollers to remove debris from the grooved surface (e.g., gum, duct tapes, sand, etc.) from the surface. Different scrapers were used for mats and runners. You were told that on average, bundles of runners and mats were scraped in 6 minutes and 3 minutes, respectively. Next, bundles of mats and runners were washed in separate machines. You were told that machine washing of runner and mat bundles is completed in 10 and 5 minutes, respectively. All washed rubber jobs were dried under pressure air and then surface-coated with a shine spray. You were advised that these activities are completed on average in 8 minutes and 4 minutes for runners and mats, respectively.

Ali’s brother, Abbas, took your group for a tour of the Plush operation, and you noted that bundles first went through a detailed wash, whereby they were washed four times with different chemicals to remove dirt and stains. Next, they were dried through heat rollers and hot air blowers and sprayed with stain guard. You were told that washing and drying plush bundles would, on average, take 15 and 20 minutes, respectively.

At the end of your tour, Ali and Abbas told you that they ensure all the rubber and plush jobs are carefully checked for quality before they are shipped to the customer. “On average, we spent about 5 minutes on each bundle to make sure the outgoing bundles are clean, dry, treated and tagged properly”. You asked them how many of each job order they receive. Ali said the number of orders slightly changes at different times of the year, but ballpark 80% of their orders are rubber jobs and 20% are for plush. You asked about the breakdown of rubber orders, and they said mats and runners each form 40% of orders.

Ali then invited you back to his office, offered you coffee. After coffee, he said: “I am rather content with my business, but at times, particularly in winter, we take more jobs and I sometimes worry that we might fall behind. I don’t know, perhaps it would be

helpful to have a map of our operation to figure out what can give us a headache and what needs to be done about it.

Source: (Haywood, 2023).

Question

How would you help him by drawing a process flow diagram of their operations?

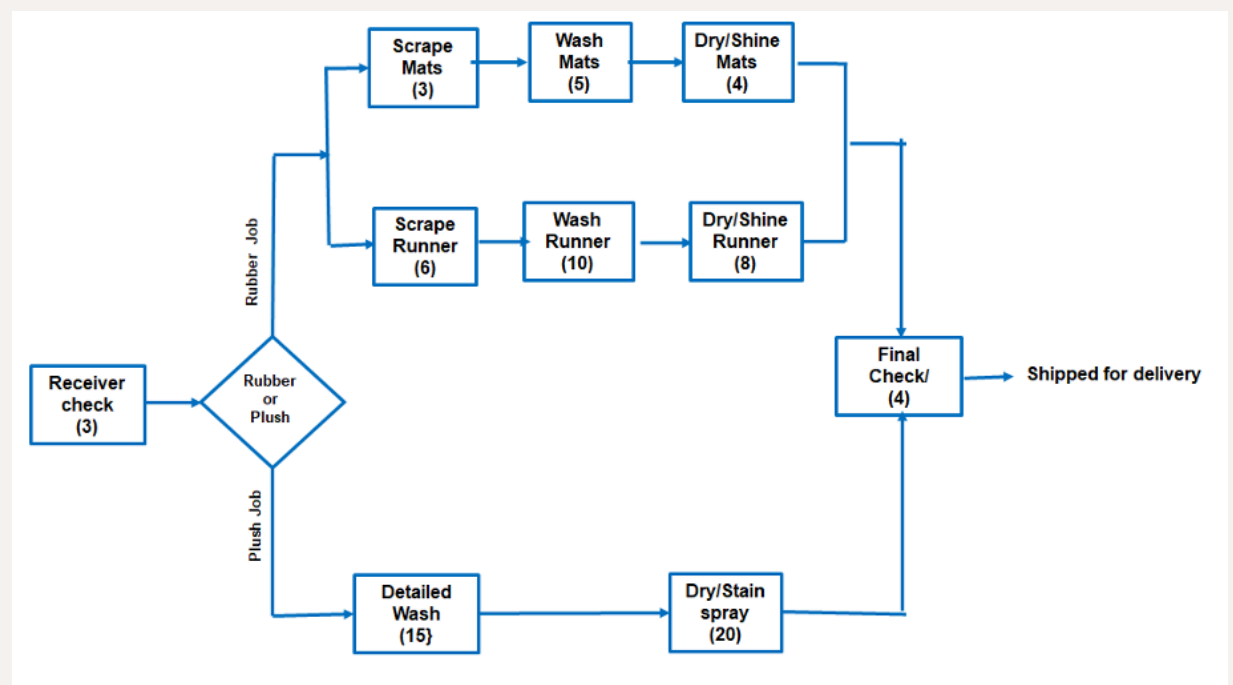


Image Description

A flowchart showing a process for handling jobs with two main paths: rubber jobs and plush jobs. The process begins with a “Receiver check (3).” A decision diamond labelled “Rubber or Plush” splits the flow. Numbers in parentheses indicate processing times or steps.

Rubber Job Path:

Two sub-paths:

- Scrape Mats (3) → Wash Mats (5) → Dry/Shine Mats (4).
- Scrape Runner (6) → Wash Runner (10) → Dry/Shine Runner (8).

Both sub-paths lead to “Final Check (4).”

Plush Job Path:

- Detailed Wash (15) → Dry/Stain Spray (20) → Final Check (4).

All paths converge at “Final Check (4)” before proceeding to “Shipped for delivery.”

5.9 KEY TERMS



Key Terms

- **Assignable Variation:** Variation due to identifiable causes such as faulty equipment or human error that can be reduced or eliminated.
- **Automation:** The use of equipment or systems to perform processes with minimal human intervention.
- **Backward Integration:** A type of vertical integration where a company gains control over its suppliers.
- **Batch Flow Process:** A process structure that produces moderate volumes of similar products in groups or batches with some flexibility and setup times.
- **Business process** is a structured network of interrelated activities that utilize available resources to transform inputs into valuable outputs.
- **Capital intensity** refers to the extent to which a production process relies on equipment and technology relative to human labour.
- **Continuous Flow Process:** A highly standardized process structure used for uninterrupted, high-volume production such as oil refining.
- **Degree of vertical integration** reflects how many of these activities a firm chooses to perform internally rather than outsourcing
- **Fixed Automation:** Hard automation used for repetitive, high-volume tasks with little flexibility.
- **Flexible Automation:** Soft automation that allows for adaptable equipment capable of handling multiple product configurations.
- **Forward Integration:** A type of vertical integration where a company gains control over distribution or retail channels.

- **Job Shop Process:** A flexible process used for small batches of custom products, often requiring skilled labour and varied workflows.
- **Labour Content:** The amount of human effort and skill required in a process.
- **Line Flow Process:** A standardized, high-volume production process with a fixed sequence of operations, typical in assembly lines.
- **Operational Processes:** These are the core value-generating activities of the business. They encompass functions such as procurement, production or service delivery, marketing, and sales.
- **Process:** A structured set of activities that transforms inputs into outputs to create value.
- **Process Charts:** A documentation tool that visually represents the steps and activities in a process along with their characteristics.
- **Process Documentation:** The recording and visualization of how work is performed to ensure consistency and facilitate improvement.
- **Process Flow Diagrams:** Visual representations showing the flow of activities and decisions within a process.
- **Process Management:** The planning, execution, control, and improvement of business processes to meet organizational goals.
- **Process Structure:** The configuration or architecture of a process, including flow, volume, flexibility, and labour requirements.
- **Process Variation:** Deviations in process outcomes due to product variety, demand shifts, randomness, or assignable causes.
- **Product Customization:** Tailoring a product or service to meet specific customer requirements, often involving customer input.
- **Project Process:** A highly flexible, low-volume process used for unique, complex tasks such as construction or software development.
- **Random Variation:** Unpredictable variation that occurs naturally in any process and cannot be completely eliminated.
- **Resource flexibility** refers to the ability of an organization's resources—namely, its workforce, facilities, and equipment—to adapt to changing operational requirements.
- **Self-Service:** A model in which customers perform tasks traditionally handled by

the service provider to reduce costs and increase convenience.

- **Strategic Implications:** The broader effects of process decisions on efficiency, cost, quality, responsiveness, and competitive advantage.
- **Structural Variation:** Predictable variation in demand, such as seasonality or market trends.
- **Supporting Processes:** Business functions like HR or IT that support core operations but do not directly add customer value.
- **Swim Lane Diagrams:** A type of process flow diagram that visually separates activities by function, role, or department.
- **Time and Location Determination:** The aspect of process design that accounts for when and where a service or product is delivered.
- **Types of Automation:** The classification of automation into fixed (hard) or flexible (soft) based on adaptability and task specificity.
- **Types of Business Processes:** Categories of processes including upper-management, operational, and supporting.
- **Types of Flexibility:** Product and volume flexibility that allow operations to handle a range of outputs and demands.
- **Types of Vertical Integration:** The forms of integration—backward, forward, and balanced—that define a firm's control over its supply chain.
- **Upper-Management Processes:** Processes that guide strategic direction and organizational governance.
- **Variable Cost:** The cost that changes with the level of output, typically higher in flexible, labour-intensive processes.
- **Volume Flexibility:** The ability to adjust output levels efficiently in response to changes in demand.

OpenAI. (2025, June 13). ChatGPT. [Large language model]. <https://www.chatgpt.com>
 Prompt: *Provide a list of key terms, with definitions, for the following content.*

CHAPTER 6: MANAGING QUALITY

Chapter Overview

[6.0 Learning Outcomes](#)

[6.1 Introduction to Quality](#)

[6.2 Gurus of Quality](#)

[6.3 Cost of Quality](#)

[6.4 Quality Systems](#)

[6.5 Tools for Quality Improvement](#)

[6.6 Chapter Summary & Review](#)

[6.7 Key Terms](#)

6.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Differentiate between design quality and process quality and explain their significant interaction in achieving overall product quality.
- Describe the historical evolution of quality management practices and articulate how consumer perceptions influence product quality and business success.
- Identify key figures in the field of quality management that contributed to the modern field of quality.
- Categorize and explain the various costs associated with quality management, including prevention costs, appraisal costs, internal failure costs, and external failure costs.
- Explain the principles and practices of Total Quality Management (TQM), ISO standards, and Six Sigma.
- Demonstrate the use of quality improvement tools such as control charts and Pareto charts in real-world scenarios.

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6.1 INTRODUCTION TO QUALITY

The Pursuit of Quality

Businesses worldwide strive relentlessly to provide quality products and services to consumers. A good quality product is considered a given by the consumer. The success of a business depends on reading and understanding consumers' perceptions regarding the quality of the product or service provided by the company. The aim of the company is to bridge any gap between the consumer's expectations regarding the quality of a product and its performance.

Defining Quality from the Consumer's Perspective

To fill or at least reduce the above-mentioned gap, the emphasis should be on identifying how a consumer measures the quality of a product or service. Similarly, how is the quality of a pen measured? Should it be measured in terms of its longevity, its price, or its performance? This chapter specifically discusses various consumer-oriented definitions of quality.

Historical Perspective

Prior to the 1980s, quality was not a primary concern for North American manufacturers. However, as high-quality goods began to flood the North American markets from Japan, it became evident that North American companies had fallen behind in this regard. Japanese products, particularly in the automotive industry, gained preference among consumers who recognized their superior level of quality.

Quality in Operations Management

In the contemporary business landscape, quality can be broadly defined as the degree to which a product or service meets or surpasses the customer's expectations. This concept holds significant importance in the field of operations management.

Determinants of Product Quality

For any product, the quality is determined by two primary factors: Design Quality and Process Quality:

Design Quality

Design quality can be described as the quality that a product has in terms of the actual characteristics of the product. Think about the design of your favourite cell phone. The decisions made by Marketing as well as the Design team will determine the way your phone will operate, the quality of the sound, and the features it has, not to mention the way it looks, feels and lasts. Below are some facets of product quality (Garvin, 1987).

Design Quality	Description	Cellphone Example
Performance	Primary operating characteristics	Clarity of sound, speed of connection
Durability	Ability to withstand damage	A dropped phone withstands damage
Reliability	Long-lasting: how long before a breakdown occurs	Several years of trouble-free performance
Features	Extra characteristics, bells, and whistles	Extra storage space, long-lasting battery
Serviceability	How easy it is to fix and how willing the organization is to repair the product	Same-day repairs, large network of locations
Reputation	Perceived image in the marketplace	High scores on global quality ratings
Aesthetics	The appearance of the product, feel, smell, taste	Sleek modern design, large screen

Process Quality

Process quality, on the other hand, focuses on the manufacturing or service delivery processes involved in producing the product or service. It involves ensuring that the processes are efficient, consistent, and capable of meeting the design specifications. Factors such as process control, quality control measures, and continuous improvement efforts contribute to achieving high process quality.

Process quality refers to the ability of the organization to produce the good or service having perfect quality at each stage of the process, or in other words, manufacturing defect-free products.

Element	Description
Raw Materials	Quality level of purchased inputs
Equipment	Capability, well maintained, flexibility
Employees	Experience, training, ability level
Technology	Matches the application

Measurement of service quality is more challenging. Each customer has a certain performance level in mind from which to compare or evaluate a service. Below are some of the commonly accepted elements by which customers evaluate service performance.

Element	Description
Tangibles	Any physical products used during the service
Reliability	Capability, well maintained, flexibility
Convenience	Experience, training, ability level
Responsiveness	Matches the application
Time	How quickly the service is delivered
Courtesy	The politeness and friendliness of employees
Consistency	Repeated consistent performance without fail
Assurance	Employees have a high level of expertise and trust

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6.2 GURUS OF QUALITY

Much of the field of Quality originated from several individuals who spent their careers researching, teaching and developing the field of Quality. These individuals are Walter Shewhart, W. Edwards Deming, Joseph Juran, Philip Crosby, and Armand Fiegenbaum.

Walter A. Shewhart (1891-1967): Pioneer of Statistical Quality Control

Dr. Shewhart, an American physicist, engineer, and statistician, is widely regarded as the father of statistical quality control (SQC). Throughout his career, he extensively researched process variation and is credited with developing the first control chart. His groundbreaking work centred on the importance of reducing variation to achieve quality improvement.

Shewhart's legacy includes the fundamental concepts of assignable and common causes of variation. All production processes exhibit some level of variation, which intuitively leads to decreased quality with increased variability. **Assignable variation** arises from identifiable and addressable causes, such as employee error, software malfunction, or equipment failure. In contrast, **common variation**, also known as chance variation, is inherent to the process and generally expected. Minimizing or eliminating either type of variation directly translates to enhanced product quality.



[“Walter Shewhart”](#), [Public Domain](#)

W. Edwards Deming (1900-1993): Champion of Quality Management

Arguably the most prominent figure among the “Quality Gurus,” Dr. Deming was an American engineer, statistician, professor, and prolific author. Following World War II, his expertise in statistical process control led him to Japan, where he was recruited to aid with their national census. From 1950 onwards, Deming's significant contribution involved training thousands of Japanese engineers, managers, and academics in fundamental statistical process control techniques. This pivotal role is widely credited with propelling Japan to become a global leader in quality manufacturing.

In recognition of Deming's profound impact, the Deming Prize, Japan's most prestigious quality award, was named in his honour. While Dr. Deming authored numerous publications, his enduring legacy is likely secured through his renowned Deming's 14 Points and the Deming Cycle, both of which continue to be foundational principles within quality management practices.

Edwards Deming's "14 Points:"

1. Create constancy of purpose toward improvement of product and service, with the aim to become competitive, to stay in business and to provide jobs.
2. Adopt the new philosophy. We are in a new economic age. Western management must awaken to the challenge, learn its responsibilities, and take on leadership for change.
3. Cease dependence on inspection to achieve quality. Eliminate the need for massive inspection by building quality into the product in the first place.
4. End the practice of awarding business on the basis of a price tag. Instead, minimize total cost. Move towards a single supplier for any one item, on a long-term relationship of loyalty and trust.
5. Improve constantly and forever the system of production and service to improve quality and productivity, and thus constantly decrease costs.
6. Institute training on the job.
7. In Institute leadership, the aim of supervision should be to help people, machines, and gadgets do a better job. Supervision of management is in need of an overhaul, as well as supervision of production workers.
8. Drive out fear so that everyone may work effectively for the company.
9. Break down barriers between departments. People in research, design, sales, and production must work as a team to foresee problems of production and usage that may be encountered with the product or service.
10. Eliminate slogans, exhortations, and targets for the workforce, asking for zero defects and new levels of productivity. Such exhortations only create adversarial relationships, as the bulk of the causes of low quality and low productivity belong to the system and thus lie beyond the power of the workforce.
 1. Eliminate work standards (quotas) on the factory floor. Substitute with leadership.
 2. Eliminate management by objective. Eliminate management by

numbers and numerical goals. Instead, substitute with leadership.

11. Remove barriers that rob the hourly worker of his right to pride of workmanship. The responsibility of supervisors must be changed from sheer numbers to quality.
12. Remove barriers that rob people in management and engineering of their right to pride of workmanship.
13. Institute a vigorous program of education and self-improvement.
14. Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job.

The **Deming Cycle** or Deming Wheel is also known as PDCA, or “Plan, Do Check, Act.” It is a version of continuous improvement that emphasizes the continuous nature of process improvement.

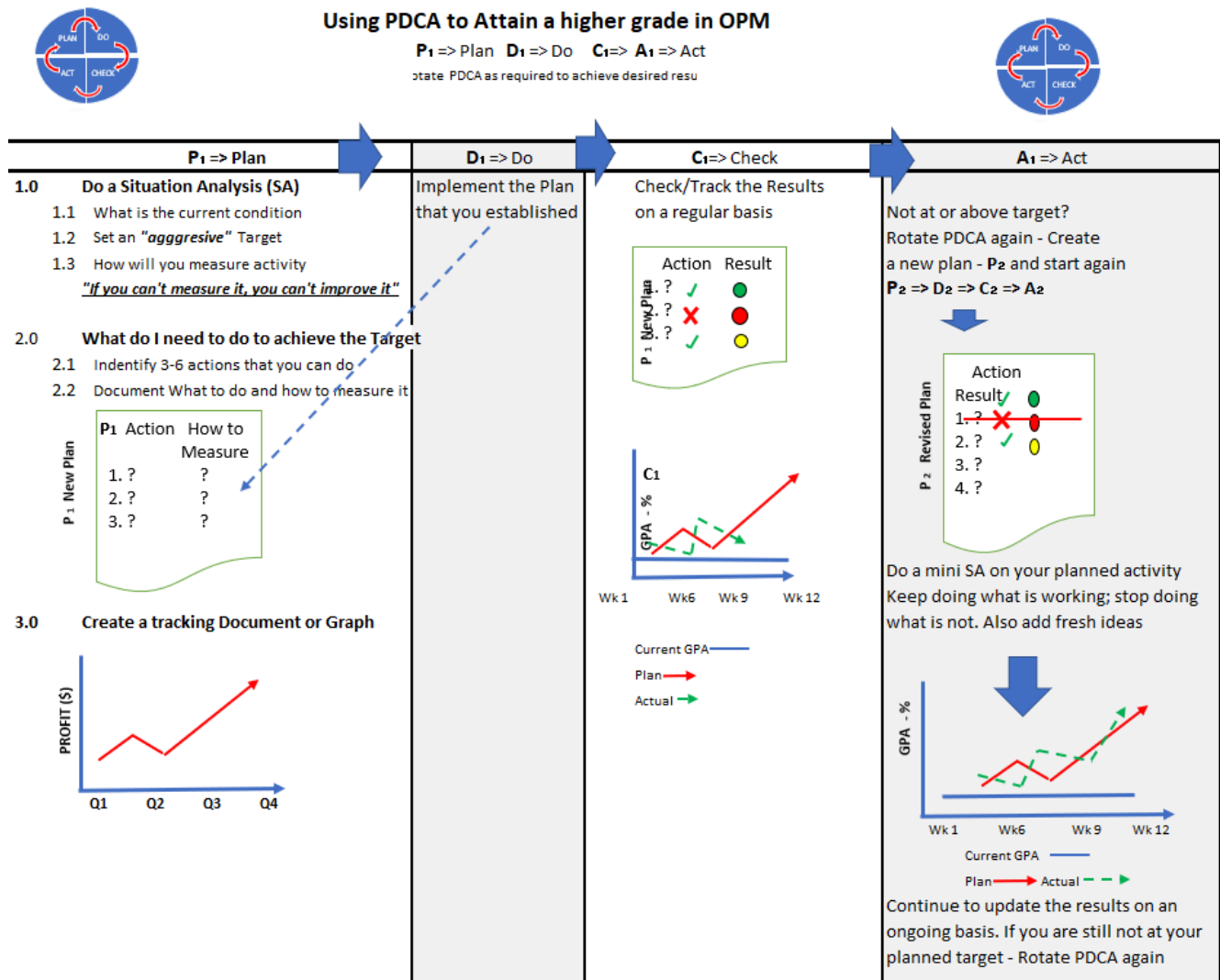


Figure 6.2.1: "An example utilizing PDCA to attain a higher grade in OPM" by Jim Philips, CC BY NC SA. [Excel Download: Accessible format for Figure 6.2.1]

Image Description

Figure 6.2.1 shows a diagram that is divided into four main sections labelled Plan (P₁), Do (D₁), Check (C₁), and Act (A₁), each represented by arrows flowing sequentially from one to the next, forming a continuous loop. The diagram emphasizes the iterative nature of the PDCA cycle, with smaller versions of the PDCA cycle shown at the top corners.

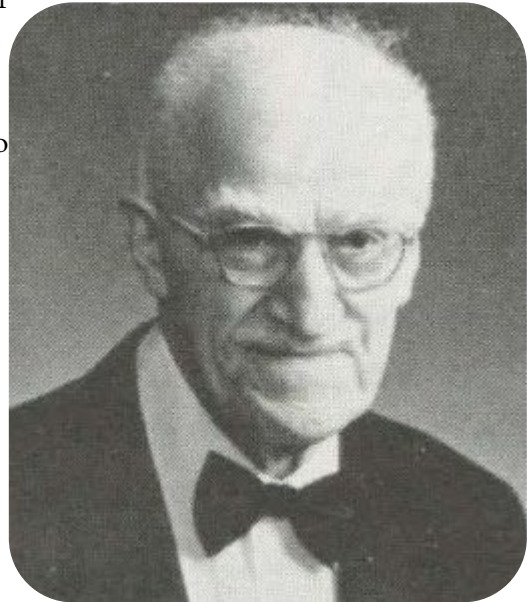
- Plan (P₁):
 - Do a Situation Analysis (SA):
 - 1.1 What is the current condition?
 - 1.2 Set an aggressive target.

- 1.3 How will you measure the activity? (Quote: “If you can’t measure it, you can’t improve it”)
- What do I need to do to achieve the target?
 - 2.1 Identify 3-6 actions that you can take.
 - 2.2 Document what to do and how to measure it.
- Create a tracking document or graph:
 - The example graph shows progress over four quarters (Q1 to Q4) with a rising trend.
- Do (D1):
 - Implement the Plan that you established
- Check (C1):
 - Check/Track the Results on a regular basis: Track progress using a document or graph.
- Act (A1):
 - Not at or above target? Rotate PDCA again:
 - Create a new plan (P2) and start again.
 - Do a mini SA on your planned activity.
 - Keep doing what is working; stop doing what is not.
 - Add fresh ideas.
 - Continue to update the results on an ongoing basis.
 - If you are still not at your planned target – Rotate PDCA again.

Joseph M. Juran (1904-2008): Quality Management Authority

Juran, a Romanian-born American engineer, established himself as a giant in the quality management field. His foundational work includes the widely influential *Quality Control Handbook*, first published in 1951. Juran championed a three-pronged approach to quality, known as the Juran Trilogy: quality planning, quality control, and quality improvement. A prolific author, he contributed hundreds of papers and 12 books to the field. Notably, Juran is credited with the concept of the **cost of quality**, a framework for understanding and managing the financial implications of quality.

Juran's influence extends beyond his own contributions. He recognized the value of Vilfredo Pareto's (1848-1923) work and popularized the **Pareto Principle**, also known as the 80/20 rule. This principle, originally an observation by Pareto that 80% of Italy's land was owned by 20% of the population, has become a cornerstone of problem-solving and continuous improvement efforts in quality management. The principle suggests that a significant portion of problems (around 80%) often stem from a relatively small number of root causes (around 20%). This realization allows organizations to focus their improvement efforts on the most impactful areas.



[“J. M. Juran”](#), [Public Domain](#)

The Pareto Principle finds numerous applications within quality management:

- *Defect concentration:* It's widely accepted that 80% of defects can be traced back to a small number (20%) of root causes. Firms benefit by prioritizing the identification and rectification of these root causes.
- *Profit distribution:* In many companies, 80% of profits might be generated by just 20% of the products or services offered. Identifying and nurturing these high-performing offerings can significantly improve overall profitability.
- *Employee engagement:* Sometimes, just 20% of employees might be responsible for generating 80% of the continuous improvement ideas. Recognizing and encouraging these valuable contributors can foster a culture of innovation within the organization.

Philip Crosby (1926-2001): Champion of "Zero Defects"

Crosby, an American businessman and author, gained recognition for his 1979 book *Quality is Free*. He challenged the prevailing notion that quality comes at a premium, arguing instead that the true costs of quality are often significantly underestimated. Crosby is credited with coining the term **zero defects**, a philosophy emphasizing the elimination of errors from the outset. He maintained that preventing defects is far more cost-effective than relying on extensive inspection, rework, and repairs after the fact.



"Philip Crosby", used under fair dealing for educational purposes (Canada).

Armand Feigenbaum (1920-2014): Architect of Total Quality Management

Dr. Feigenbaum, an American quality engineer and businessman, served as the Director of Manufacturing Operations at General Electric from 1958 to 1968. He is credited with pioneering the concept of total quality control, which later evolved into the widely adopted total quality management (TQM) philosophy. Feigenbaum also introduced the thought-provoking concept of the "**hidden plant**", which refers to the

untapped productive capacity lost due to inefficiencies, defects, and rework. His work highlighted the significant potential for improvement that lies within existing operations.

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6.3 COST OF QUALITY

Organizations that deliver high-quality goods and services can achieve a competitive edge and distinguish themselves in the marketplace. These companies often experience higher profitability, as they incur minimal losses and additional expenses related to poor productivity, rework, inspections, and scrap.

The costs associated with maintaining and improving quality can be categorized into four main types: prevention costs, appraisal costs, and failure costs. Failure costs are further divided into internal failure costs and external failure costs. Understanding and managing these cost categories is crucial for optimizing quality management and enhancing overall operational efficiency.

Prevention costs

Prevention costs encompass all expenditures aimed at proactively avoiding the occurrence of defects or non-conformities in products or services. These costs are incurred through initiatives such as quality improvement programs, employee training and development, equipment upgrades, implementation of quality management systems, and proactive design modifications. Investing in prevention activities can significantly reduce the likelihood of defects and associated costs further down the production process.

Appraisal costs

Appraisal costs refer to the resources dedicated to inspecting, testing, and evaluating products or services during the production or delivery process. These costs include wages for quality inspectors, expenses related to testing laboratories and equipment, gauging and measurement activities, and process control mechanisms. Appraisal activities aim to identify and eliminate defects before they reach the customer, thereby preventing potential failure costs.

Internal failure costs

Internal failure costs arise when defects or non-conformities are detected within the organization before the product or service is delivered to the customer. These costs encompass rework efforts to rectify identified defects and the costs associated with scrapping or disposing of products that cannot be repaired or reworked. Internal failure costs include potential disruptions to production schedules, expedited manufacturing efforts to compensate for scrapped products, and the associated opportunity costs.

External failure costs

External failure costs are incurred when defective products or non-conforming services reach the customer. These costs can be substantial and may include expenses related to product replacements, expedited shipping, product recalls, potential legal liabilities, and the detrimental impact on customer satisfaction and future business opportunities. External failure costs are often challenging to quantify precisely due to the intangible nature of lost customer goodwill and its long-term implications on an organization's reputation and market position.

By understanding and effectively managing these cost categories, organizations can optimize their quality management efforts, minimize defects and non-conformities, and ultimately enhance customer satisfaction while reducing overall operational costs.

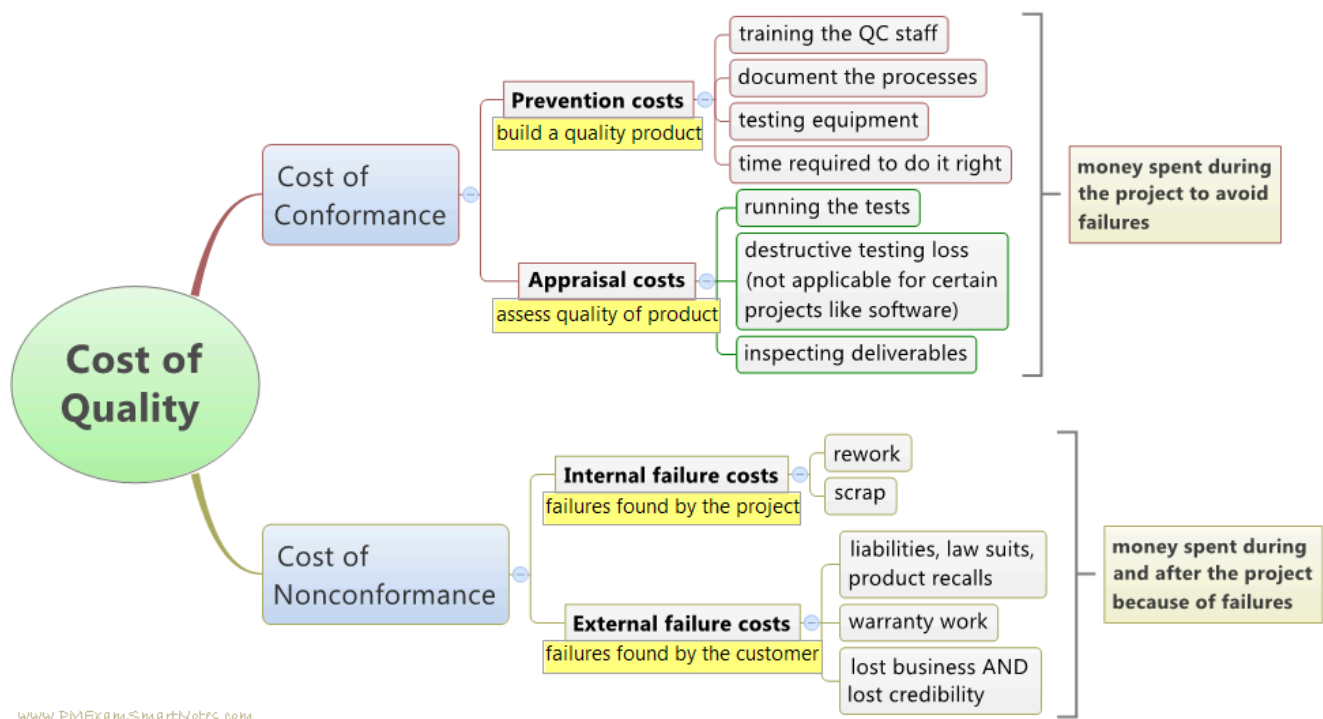


Figure 6.3.1: "Cost of Quality" by pmexamsmartnotes.com, CC BY-NC-ND 2.0

Image Description

Cost of Quality

1. **Cost of Conformance:** Money spent during the project to avoid failures.

- **Prevention Costs:** Costs to build a quality product.
 - Training the QC staff

- Documenting the processes
- Testing equipment
- Time required to do it right
- **Appraisal Costs:** Costs to assess the quality of the product.
 - Running the tests
 - Destructive testing loss (not applicable for certain projects like software)
 - Inspecting deliverables

2. **Cost of Nonconformance:** Money spent during and after the project because of failures.

- **Internal Failure Costs:** Failures found by the project.
 - Rework
 - Scrap
- **External Failure Costs:** Failures found by the customer.
 - Liabilities, lawsuits, product recalls
 - Warranty work
 - Lost business and lost credibility

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6.4 QUALITY SYSTEMS

Many organizations employ various quality systems to manage and enhance their quality standards. Three common quality systems are Total Quality Management (TQM), ISO 9001, and Six Sigma.

Total Quality Management (TQM)

In today's competitive environment, companies must deliver high-quality goods and services that meet or exceed customer expectations. **Total Quality Management (TQM)**, also known as quality assurance, encompasses all the steps a company takes to ensure its products or services align with customer-defined specifications and maintain high quality.

TQM principles generally focus on three key areas:

1. Customer satisfaction
2. Employee involvement
3. Continuous improvement

Let's delve deeper into these principles.

Customer Satisfaction

Organizations committed to TQM recognize that the primary goal of a business is to generate profit by fulfilling customer needs. They allow customers to define quality by identifying and offering product features that meet their requirements. These companies actively seek customer feedback to understand how to produce goods and services that function correctly and meet expectations.

To ensure quality is integrated into every aspect of their operations—from design and product

planning to sales and service—companies often use surveys and other methods to monitor customer satisfaction. By tracking feedback over time, they can identify areas for improvement.

Employee Involvement

Effective TQM requires the commitment of everyone in the organization, not just upper management, to satisfy the customer. For instance, if customers experience long wait times at a drive-through, multiple employees are responsible, not just the manager. Similarly, a defective DVD is not solely the responsibility of the quality control department but of every employee involved in its design, production, and shipping.

Managers must communicate the importance of quality to all employees and motivate them to focus on customer satisfaction. Employees need proper training to perform their jobs effectively and to identify and correct quality issues. In many organizations, employees working in similar roles form teams, often called quality circles, to identify work-related problems, propose solutions, and collaborate with management to implement their recommendations.

Continuous Improvement

A core component of TQM is continuous improvement, which involves a commitment to constantly enhancing the design, production, and delivery of goods and services. There are always opportunities to increase efficiency, reduce costs, and improve customer service and satisfaction. Everyone in the organization is encouraged to seek ways to do things better.

By adhering to these TQM principles, organizations can consistently deliver high-quality products and services that meet customer needs and maintain a competitive edge in the market.

ISO Standards

The International Organization for Standardization (ISO) is an independent, non-governmental organization that develops and publishes voluntary international standards. Founded in 1947 and

headquartered in Geneva, Switzerland, ISO operates in 164 countries and is the largest developer of international standards.

The primary objective of ISO standards is to promote global proprietary, industrial, and commercial standards that facilitate trade and ensure the safety, reliability, and quality of products and services. By enabling direct comparisons between products from different markets, these standards assist businesses in entering new markets and contribute to developing fair global trade practices.

Additionally, ISO standards serve to safeguard consumers and end-users by ensuring that certified products and services conform to internationally established minimum standards. Using these standards helps organizations create safe, reliable, and high-quality offerings while increasing productivity and minimizing errors and waste.

Video: “[What ISO standards do for you](#)” by [ISO](#) [2:05] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Steps in Obtaining ISO Certification

To obtain ISO certification, an organization must follow a structured process:

1. *Documentation and Implementation:* The organization must document and implement its quality management systems, including policies, procedures, and work instructions. This documentation process can be time-consuming and requires collaboration from all employees.
2. *Quality Manual:* The organization must develop a Quality Manual that outlines how it will ensure the quality of its goods and services.
3. *Employee Training:* All employees involved in the documented processes must receive comprehensive training to gain a full understanding of the new work procedures and documentation.

The cost and duration of this process depend on the size and complexity of the organization. Many firms choose to engage external consultants to guide and assist them throughout the process, which typically takes 12 to 18 months. ISO certification is valid for three years, after which the organization must undergo a recertification process.

While some organizations pursue ISO certification primarily due to customer requirements, the intrinsic motivation should be a genuine desire to improve internal performance and quality standards.



[News Article: Does ISO certification improve financial performance?](#)

What Benefits Are There to Obtaining ISO Certification?

ISO (International Organization for Standardization) certification is a globally recognized standard demonstrating an organization's commitment to quality, efficiency, and continuous improvement. Pursuing and maintaining ISO certification can provide organizations with the following benefits:

- *Enhanced Quality Management:* ISO standards, such as ISO 9001, provide a framework for establishing a robust quality management system (QMS). Organizations can streamline their processes by implementing these standards: identifying and monitoring key performance indicators and maintaining consistent quality standards across their operations. This leads to improved product or service quality, increased customer satisfaction, and a competitive advantage in the market.
- *Operational Efficiency and Cost Savings:* Adhering to ISO standards encourages organizations to optimize processes, reduce waste, and improve overall efficiency. Organizations can achieve cost savings, increased productivity, and a more agile and responsive operational structure by identifying and eliminating non-value-adding activities.
- *Risk Management and Compliance:* ISO standards emphasize risk-based thinking and provide guidelines for identifying, assessing, and mitigating potential risks. Organizations can proactively manage risks, ensure regulatory compliance, and protect their employees, assets, and reputation by implementing standards like ISO 31000 (Risk Management) and ISO 45001 (Occupational Health and Safety Management System).
- *Expanded Market Access:* ISO certifications serve as a globally recognized symbol of quality and compliance. Organizations that achieve ISO certifications, such as ISO 9001 or ISO 13485

(Medical Devices), demonstrate their commitment to meeting internationally recognized standards. This enhances credibility and opens doors to new markets by reassuring customers, suppliers, and partners about the organization's dedication to quality and industry best practices.

- *Continuous Improvement Culture:* ISO standards foster a culture of continuous improvement by promoting the Plan-Do-Check-Act (PDCA) cycle. Organizations that embrace ISO standards are encouraged to regularly evaluate their processes, measure performance, and implement corrective actions. This iterative approach drives ongoing optimization, innovation, and the pursuit of excellence within the organization.
- *Increased Customer Confidence:* ISO standards instill confidence by ensuring organizations follow standardized processes, prioritize customer satisfaction, and deliver reliable products or services. Standards like ISO 27001 (Information Security Management System) and ISO 22301 (Business Continuity Management System) address data security and business continuity, strengthening customer trust in handling sensitive information and ensuring uninterrupted operations.
- *Improved Communication and Corporate Culture:* Implementing ISO standards promotes better communication and alignment within the organization. By having a set of standardized processes and quality objectives, employees clearly understand their roles and responsibilities, leading to improved collaboration and a stronger corporate culture focused on quality and customer satisfaction.

By pursuing and maintaining ISO certification, organizations can enhance their operations, reduce risks, and gain a competitive edge in the market, making it a valuable investment for operations management professionals. (Diesing, 2023; Onspring, n.d.)

Read the article below from the Business Development Bank of Canada.



[Short Article: Seven ways ISO certification can help your business](#)

Hazard Analysis Critical Control Point (HACCP)

HACCP is a quality management system specifically designed for organizations in the food processing industry. Implementing a HACCP program can yield several significant benefits:

- *Gain Customer Confidence:* Demonstrating a commitment to food safety can enhance customer trust.
- *Sharpen Competitive Edge and Develop New Export Opportunities:* Adhering to HACCP standards can differentiate your business and open up new markets.
- *Achieve More Rigorous Quality Control:* Implementing HACCP ensures that stringent quality control measures are in place.
- *Reduce Waste and Spoilage:* Effective management of food safety risks can minimize waste and spoilage.
- *Control Contamination Risks and Recall Processes:* HACCP helps identify and control contamination risks, thereby streamlining recall processes if necessary.
- *Build Awareness of Hygiene and Safety for Employees:* Training employees on HACCP principles increases their awareness of hygiene and safety practices.
- *Eliminate Potential Allergen Issues:* HACCP helps identify and manage potential allergen risks.

The Seven Principles of HACCP

The seven principles of HACCP outline the steps necessary to manage and control food safety risks within a business:

1. *Conduct a Hazard Analysis:* Identify potential hazards affecting food safety.
2. *Identify Critical Control Points (CCPs):* Determine the points in the process where hazards can be prevented, eliminated, or reduced to safe levels.
3. *Establish Critical Limits:* Set maximum or minimum limits for each CCP to ensure food safety.
4. *Monitor Critical Control Points:* Implement procedures to monitor CCPs and ensure they remain within the established limits.
5. *Establish Corrective Actions:* When monitoring indicates a CCP is not within the established limits, define actions to be taken.
6. *Establish Record-Keeping Procedures:* Maintain documentation and records to demonstrate compliance with HACCP principles.
7. *Establish Verification Procedures:* Implement procedures to verify that the HACCP system is working effectively.

Ensuring the safety of customers is paramount for any food business. Organizations can control food safety risks and protect against foodborne illness outbreaks by implementing a successful HACCP program. Since

2005, it has been mandatory for federally registered meat and poultry establishments to become HACCP-certified. The Canadian Food Inspection Agency also recommends HACCP compliance certification for all businesses within the food supply chain.

Video: “[HACCP – Making Food Products Safe, Part 1](#)” by [Alberta Agriculture and Irrigation](#) [15:06] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Six Sigma

In your career, you may find yourself working in an organization that has adopted a Six Sigma program. **Six Sigma** is a comprehensive set of techniques and tools designed for process improvement. It was introduced by engineer Bill Smith at Motorola in 1980. The primary goal of Six Sigma is to achieve business success by minimizing variation in business processes. The term “Six Sigma quality” refers to a process that is so well-controlled that it produces no more than 3.4 defects per million opportunities.

The concept of Six Sigma is rooted in statistics, where “sigma” denotes standard deviation, a measure of variation within a dataset. Typically, a company process might operate at a 3-sigma quality level, meaning that 99.73% of all output falls within plus or minus three standard deviations from the mean. This results in 0.27% of all outputs being non-conforming or defective, which equates to 2,700 defects per million opportunities. Such a defect rate is unacceptable in industries where quality is critical to customer safety, such as manufacturing aircraft, automobiles, or medical devices. In contrast, a Six Sigma process achieves 99.99966% defect-free outputs.

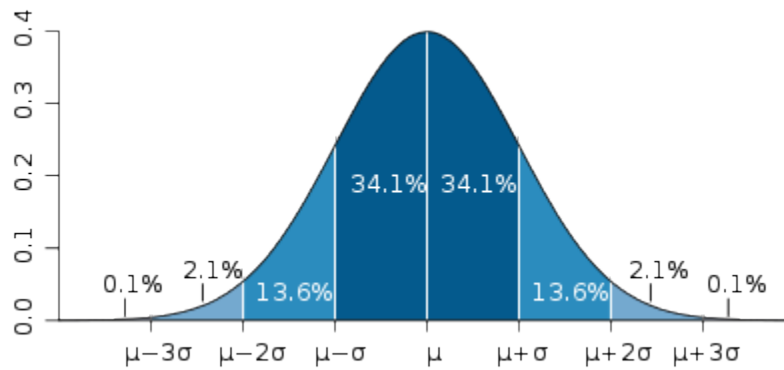


Figure 6.4.1: “[Normal distribution diagram utilizing Six Sigma](#)” by Ainali, CC BY-SA 3.0

The DMAIC Improvement Model

Unique to Six Sigma is the **DMAIC Improvement Model**, which stands for Define, Measure, Analyze, Improve, and Control. In Six Sigma, improvements are driven by project teams assembled to address quality issues, streamline existing processes, or develop new processes. The DMAIC model guides these teams through a structured approach to process improvement (American Society for Quality, n.d.):

1. *Define*: Identify the problem by understanding who the customer is, what their needs are, and what is most important to them. Determine the most suitable project to improve and meet customer requirements.
2. *Measure*: Assess current process performance by collecting data and comparing it to the desired state. Use tools like Pareto charts to analyze the frequency of problems or causes.
3. *Analyze*: Investigate the process to identify why defects are occurring and determine the causes of variation and poor performance. Conduct root cause analysis to pinpoint these issues.
4. *Improve*: Enhance process performance by eliminating the causes of defects. Modify the process and measure the results to ensure the problem has been resolved.
5. *Control*: Implement a plan to maintain the improved process and ensure that the gains are sustained over time.

By following the DMAIC model, organizations can systematically improve their processes, reduce defects, and enhance overall quality, leading to increased customer satisfaction and business success.



Figure 6.4.2: “Cyclical diagram of the DMAIC model” by Sanaz Habib, [CC BY-NC-SA 4.0](#).

Six Sigma Belt Levels

Another unique aspect of Six Sigma is the use of a belt system, similar to martial arts, to symbolize an individual’s level of expertise and proficiency in Six Sigma methodologies. The belt levels are as follows:

- **Green Belt:** A Green Belt designation indicates that an individual has received Six Sigma training. Green Belts typically have full-time roles within the organization but are called upon to assist with Six Sigma projects part-time. They support project teams by applying Six Sigma tools and techniques under the guidance of more experienced Black Belts.
- **Black Belt:** A Black Belt is a full-time position within the quality department, where the individual works exclusively as a coach and leader for Six Sigma projects. Black Belts possess extensive experience in Six Sigma methodologies and spend the majority of their time leading project teams, providing guidance, and ensuring the successful implementation of Six Sigma initiatives.

- **Master Black Belt:** A Master Black Belt is a full-time position within the Six Sigma team, with extensive experience managing and overseeing Six Sigma projects. Master Black Belts serve as coaches and mentors to Black Belts, providing advanced training, guidance, and support in implementing complex Six Sigma projects.
- **Champion:** A Champion is typically a senior manager or executive overseeing the Six Sigma program and its associated personnel. Champions are responsible for determining which projects should be prioritized, ensuring proper allocation of resources, and removing any roadblocks that may hinder the success of Six Sigma initiatives. They play a crucial role in promoting and supporting the Six Sigma culture within the organization.

This belt system recognizes an individual's level of expertise and defines their roles and responsibilities within the Six Sigma program. It fosters a structured approach to continuous improvement. It ensures that Six Sigma projects are led by qualified and experienced professionals, ultimately contributing to the organization's overall quality and operational excellence.

LEAN SIX SIGMA ORGANIZATION STRUCTURE

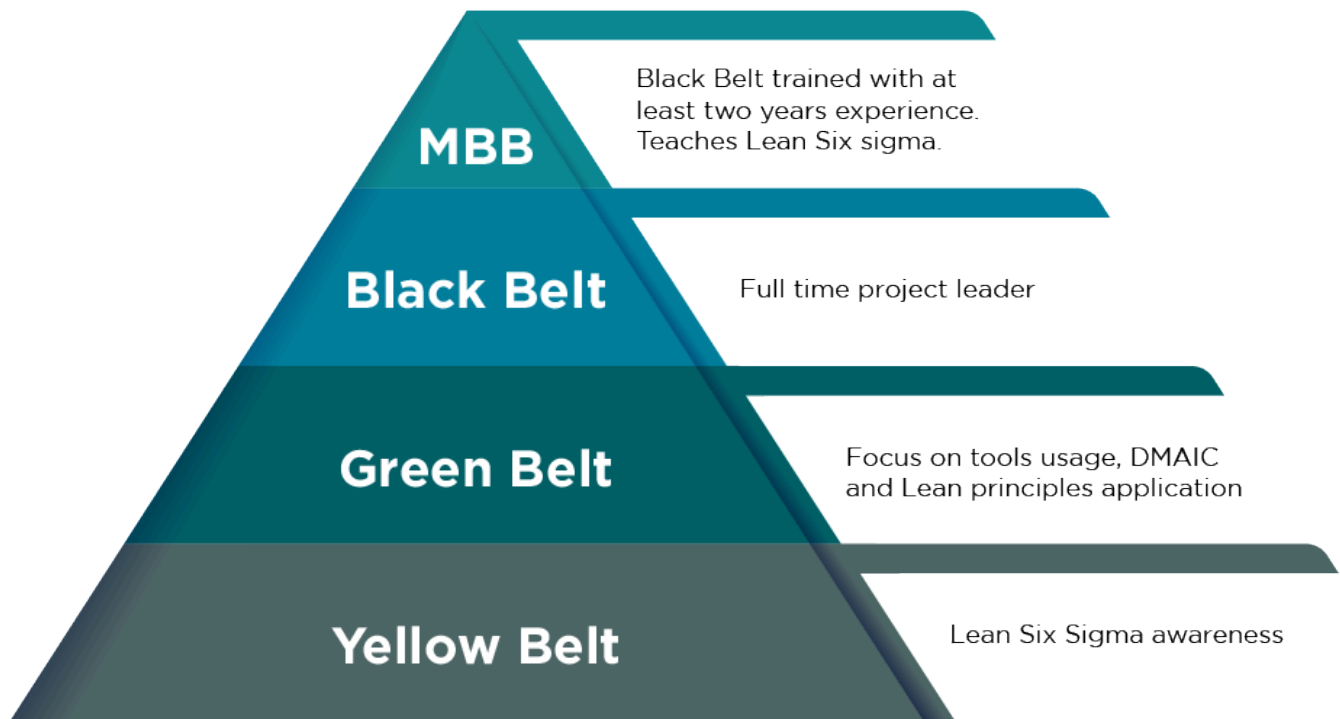


Figure 6.4.3: “[Variation of belt colours associated with Six Sigma](#)” by [Zirguezzi](#), [CC0 1.0](#). Mods: re-coloured by Fanshawe College

Image Description

The image displays the organizational structure of a Lean Six Sigma system. It features a pyramid-shaped hierarchy with different belt levels, including Master Black Belt (MBB), Black Belt, Green Belt, and Yellow Belt. The MBB is described as a Black Belt trained with at least two years of experience, who teaches Lean Six Sigma. The Black Belt is a full-time project leader, the Green Belt focuses on tools usage, DMAIC, and Lean principles application, and the Yellow Belt has Lean Six Sigma awareness.

“[6.4 Quality Systems](#)” from [Fundamentals of Operations Management](#) by Azim Abbas and Seyed Goosheh is licensed under a [Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License](#), except where otherwise noted.

6.5 TOOLS FOR QUALITY IMPROVEMENT

In any quality improvement initiative, data collection and evaluation play a critical role. Several basic, generic tools are commonly used to facilitate data analysis and drive continuous improvement efforts. These tools include check sheets, histograms, control charts, Pareto charts, scatter diagrams, and cause-and-effect diagrams.

Check Sheets

A **check sheet** is a custom-designed form used to record the frequency or number of occurrences of a particular event or outcome of interest. It can capture various types of information, such as the number of incidents, timing, or measurements that deviate from the desired specifications. Check sheets provide a structured way to collect and organize data, enabling further analysis and identification of patterns or trends.



Example: Motor Assembly Check Sheet

Name of Data Recorder: Lester B. Rapp

Location: Rochester, New York

Data Collection Dates: 1/17 – 1/23

Defect Types/ Event Occurrence	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total
Supplied parts rusted								20
Misaligned weld								5
Improper test procedure								0
Wrong part issued								3
Film on parts								0
Voids in casting								6
Incorrect dimensions								2
Adhesive failure								0
Masking insufficient								1
Spray failure								5
TOTAL		10	13	10	5	4		

Histograms

A **histogram** is a graphical representation that displays the distribution of a dataset by grouping the data into bins or intervals along the horizontal axis and showing the frequency or count of observations in each bin on the vertical axis. Histograms are useful for visualizing a dataset's shape, central tendency, and spread, which can help identify potential issues or areas for improvement.

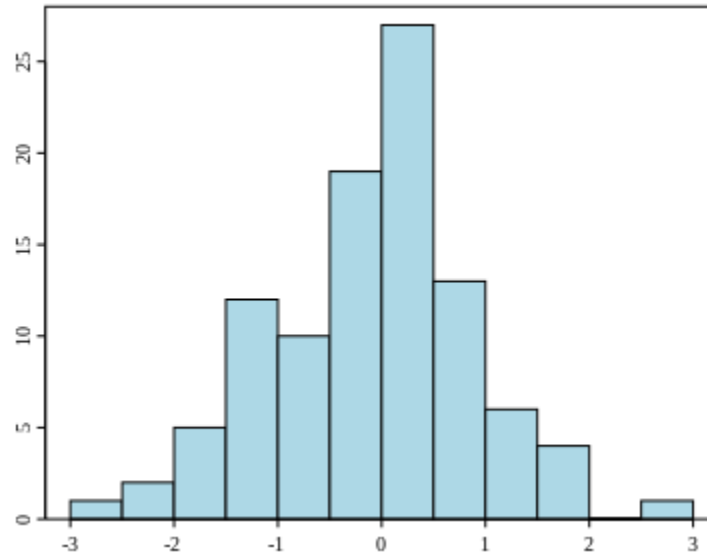


Figure 6.5.1: “Histogram diagram example”

Image Description

The image shows a histogram, which is a graphical representation of the distribution of numerical data. The x-axis represents different numerical values, while the y-axis shows the frequency or count of each value. The histogram has several bars of varying heights, with the tallest bar reaching around 24 on the y-axis.

Pareto Charts

A **Pareto chart** is a specialized type of bar chart that displays the frequency of occurrences for various characteristics, arranged in descending order from highest to lowest. The X-axis represents each characteristic, while the Y-axis on the left side indicates the number of times each occurrence was recorded. Additionally, a cumulative percentage line is plotted to show the cumulative contribution of each category to the total. The Y-axis on the right side of the chart corresponds to the percentage values on this line.

In quality management, it is crucial for managers to allocate resources effectively to address the most frequently occurring problems. Pareto analysis helps focus attention on the most common defects, enabling managers to prioritize and allocate resources to rectify these issues efficiently. This approach is based on the

Pareto principle, which suggests that a small number of causes often account for a large proportion of the effects.

Video: “[How to Make a Pareto Chart in Excel](#)” by [David McLachlan](#) [12:16] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Steps in a Pareto Analysis

1. Collect your raw data and put it into a simple table in descending order. Sum the total number of results at the bottom of the column.

Complaints	Number
Long wait time	81
Food not hot	48
Server unknowledgeable	20
Bill inaccurate	16
Floor not clean	9
Menu items sold out	7

2. Include a cumulative column and calculate the cumulative percentage of each.

Complaints	Number	Cumulative	Cumulative Percent
Long wait time	81	81	44.8
Food not hot	48	129	71.3
Server unknowledgeable	20	149	82.3
Bill inaccurate	16	165	91.2
Floor not clean	9	174	96.1
Menu items sold out	7	181	100.0

3. In EXCEL, your Pareto analysis will look like this.

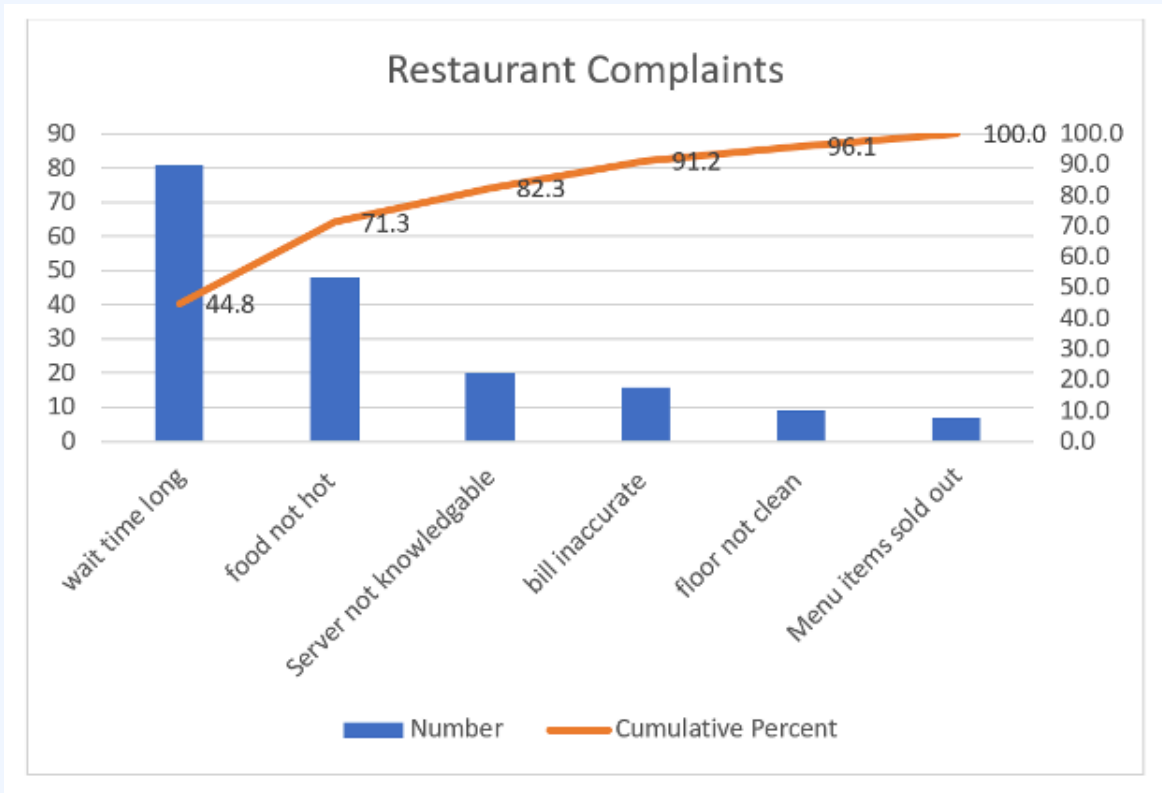


Figure 6.5.2: "Pareto Analysis of Restaurant Complaints"

Scatter Diagrams

A **scatter diagram** is a graphical representation that displays the relationship between two variables by plotting their values as a series of points on a Cartesian coordinate system. Scatter diagrams can reveal patterns, trends, or correlations between the variables, which can aid in identifying potential causes or factors influencing a particular outcome.

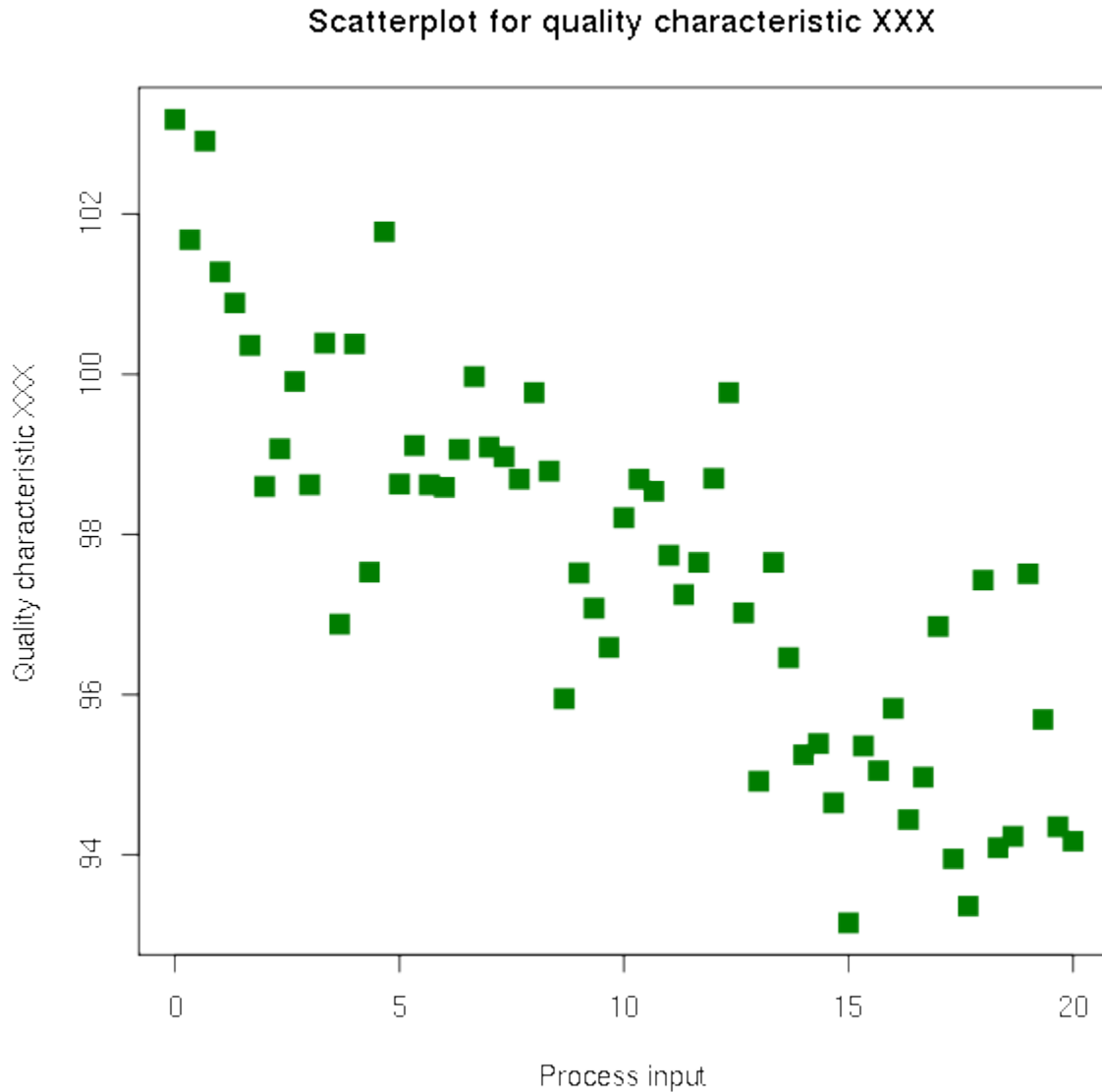


Figure 6.5.3: “Scatter diagram example” by [DanielPenfield](#), [CC BY-SA 3.0](#)

Cause and Effect Diagrams

Also known as Fishbone diagrams, **cause-and-effect diagrams** were developed by Dr. Kaoru Ishikawa to help identify the root causes of a problem. The diagram’s overall shape resembles a fish’s, with the “head” pointing to the effect or problem being analyzed. Each “rib” of the fishbone represents a major cause or category that could potentially contribute to the problem.

Common categories used in Fishbone diagrams include:

- *Man (People)*: Factors related to human resources, such as skills, training, and behaviour.

- *Method*: Factors related to processes, procedures, and techniques.
- *Material*: Factors related to raw materials, components, and supplies.
- *Machine*: Factors related to equipment, tools, and technology.
- *Environment*: Factors related to the physical and organizational environment.

Specific factors that fall under each category are written along the corresponding rib. This structured approach helps teams systematically explore and organize potential causes, facilitating a comprehensive analysis of the problem and aiding in the identification of root causes.

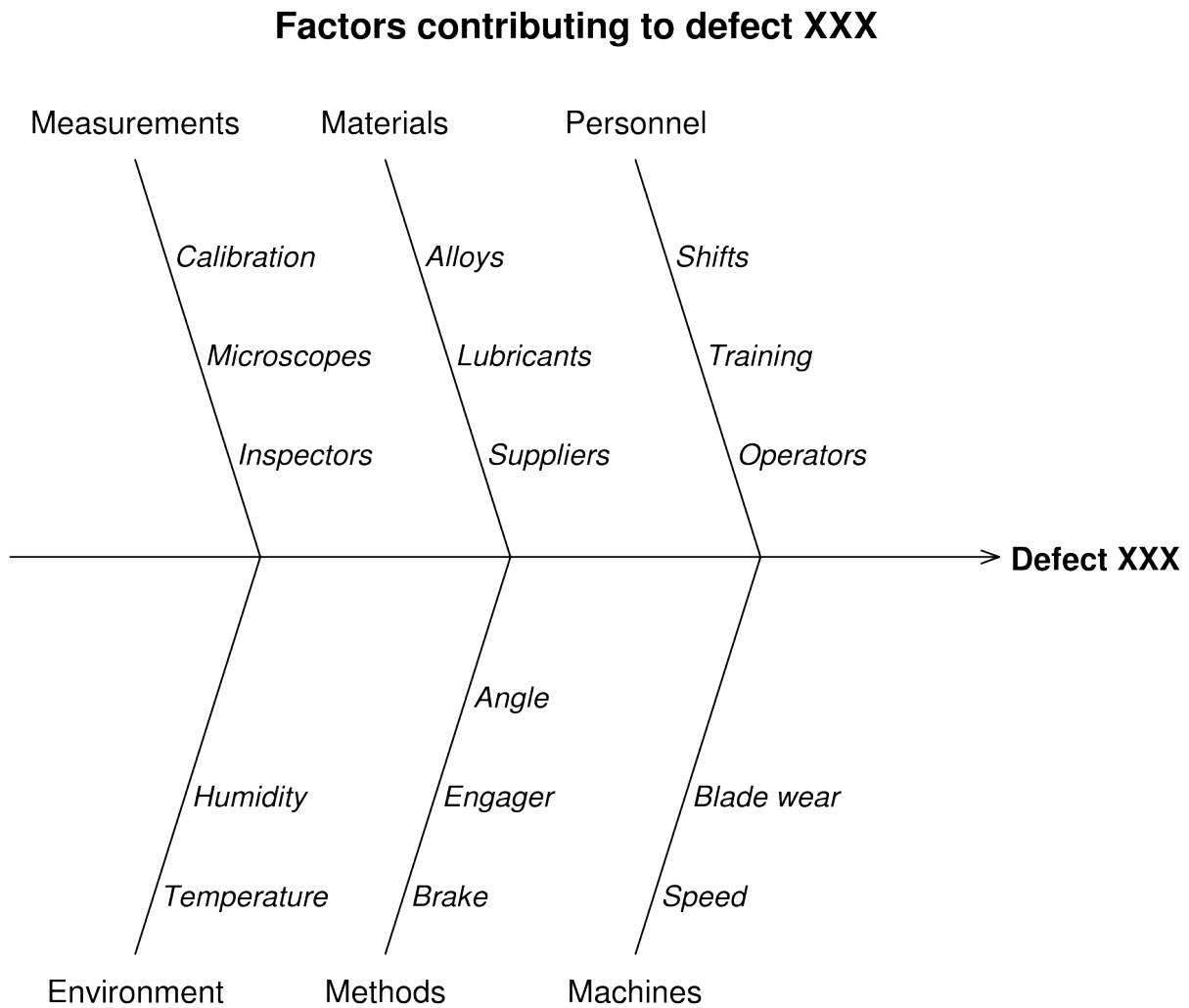


Figure 6.5.4: “Cause and effect diagram example” by DanielPenfield, CC BY-SA 3.0

Image Description

An Ishikawa or fishbone diagram illustrating the potential causes of a defect labelled ‘XXX’ at the fish head.

The major cause categories shown as the 'bone' ribs are Measurements, Materials, Personnel, Environment, Methods, and Machines. Specific factors contributing to the defect are listed as sub-branches under each main rib category.

Control Charts

A **control chart** is a statistical tool used to monitor and control the quality of a product or process. It is a graphical representation that depicts whether the sample quality falls within the normal range of variation. The normal range of variation is defined by control chart limits. Control charts were first devised by Dr. Walter A. Shewhart in 1924, also known as Shewhart charts.

A control chart has upper and lower control limits within which deviations from the mean value are allowed. The process is considered out of control if the data plotted reveals that one or more samples fall beyond the control limits. The two lines on the control chart indicate the tolerance limits within which the variation of quality is acceptable.

The upper and lower control limits separate common-cause variation inherent to the process from assignable causes of variation, which are special causes requiring investigation and corrective action. If the plotted points fall outside the tolerance limits (UCL and LCL), the process is considered out of control, and the sample is rejected. This situation warrants the determination of assignable causes, such as poor material quality, operator negligence, or defective machinery, and immediate actions are initiated to improve the quality.

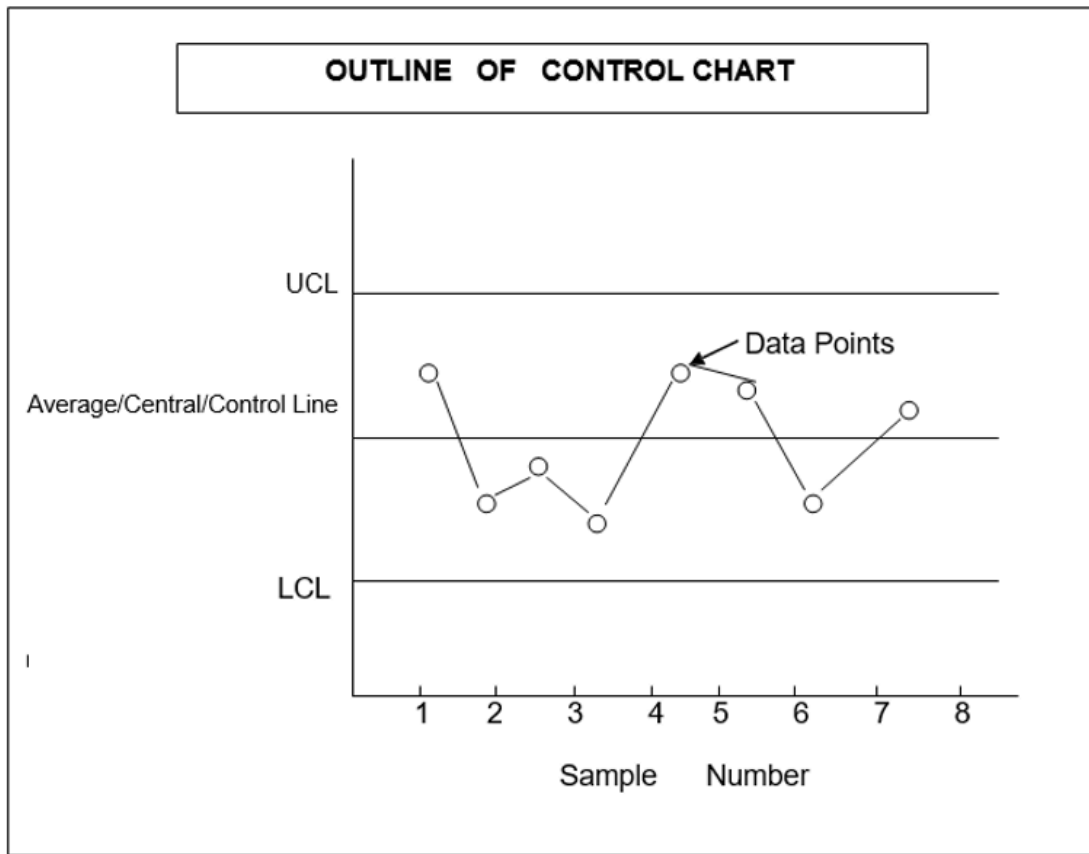


Figure 6.5.5: "Control Chart Example" by Kajal Kiran, [CC BY-NC 4.0](#).

There are two main types of control charts:

1. Control Charts for Variables
2. Control Charts for Attributes

The following video shows how to construct a control chart:

Video: “[Making a Control Chart in Excel \(with dynamic control lines!\)](#)” by [David McLachlan](#) [11:03] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Control Charts for Variables

Control charts for variables are further classified into three types:

1. **Mean ($\bar{X}$) Chart:** This chart monitors the process mean or average value of the quality characteristic.
2. **Range (R) Chart:** This chart monitors the range or the difference between the highest and lowest values within a sample or subgroup.
3. **Standard Deviation (σ) Chart:** This chart monitors the process variability by tracking the standard deviation of the quality characteristic.

Control charts are powerful tools for monitoring process performance, detecting deviations from expected behaviour, and enabling timely corrective actions to maintain quality standards.

Control Charts for Attributes

When the quality characteristic of a product cannot be quantified or measured on a continuous scale, control charts for attributes are used. Attributes are parameters that can only be identified by their presence or absence from the product, such as air bubbles, scratches, or defective prints on cloth.

Control charts for attributes are classified into three types:

1. Control Charts for Proportion of Defective Units (P-Chart)
2. Control Charts for Number of Defectives (np-Chart)
3. Control Charts for Number of Defects (C-Chart)

Control Charts for Proportion of Defective Units (P-Chart)

P-charts, or fraction defective charts, are useful when the quality characteristic cannot be quantified, such as holes in cloth or the absence of picture quality. These charts are designed to control the percentage or proportion of defective units in a lot or sample. The P-chart monitors the fraction or proportion of defective items in a sample or subgroup, allowing for the detection of shifts or trends in the process performance. It helps identify when the proportion of defective units deviates from the expected or acceptable level, enabling corrective actions to be taken.

Control Charts for Number of Defectives (np-Chart)

The **np-chart** monitors the number of defective items or units in a sample or subgroup of constant size. It is particularly useful when the sample size varies, as it accounts for the varying sample sizes by plotting the actual number of defective units.

The np-chart helps detect shifts or trends in the number of defective units, indicating when the process deviates from the expected or acceptable level of defectives. It aids in identifying potential issues and taking corrective actions to maintain the desired quality level.

Control Charts for Number of Defects (C-Chart)

The **C-chart**, or count chart, monitors the number of defects or non-conformities in a sample or subgroup of constant size. It is particularly useful when the quality characteristic of interest is the number of defects or non-conformities rather than the number of defective units.

The C-chart helps detect shifts or trends in the number of defects or non-conformities, indicating when the process deviates from the expected or acceptable level. It aids in identifying potential issues and taking corrective actions to reduce the number of defects and maintain the desired quality level.

By using the appropriate control chart for attributes, organizations can effectively monitor and control quality characteristics that cannot be measured continuously, ensuring that products or services meet the desired quality standards.

Identifying and Eliminating Variations

One of the primary goals of using control charts is to monitor and improve process quality by identifying and eliminating sources of variation. Variations can be categorized into two types: common causes and special causes.

Understanding and distinguishing between these types is essential for effective quality control and improvement.

Common Causes

Common causes, also known as chance causes or noise, are the natural and random fluctuations inherent in a stable and predictable process. These variations affect every observation and are unavoidable unless the process itself is changed. Examples include slight differences in raw materials, temperature, humidity, or machine settings. A process influenced only by common causes is considered to be in control.

Special Causes

Special causes, also known as assignable causes or signals, are abnormal and non-random fluctuations due to external factors. These variations affect only some observations and are avoidable by identifying and addressing the root causes. Examples include a broken machine, defective raw materials, power outages, or human errors. A process affected by special causes is considered to be out of control.

Detecting Special Causes

Control charts plot process data over time and compare it with control limits, representing the expected range of variation due to common causes. If data points fall within the control limits, the process is in control and only affected by common causes. If data points fall outside the control limits or show a non-random pattern, the process is out of control and affected by special causes. Identifying these patterns allows for timely corrective actions to improve process quality. (FasterCapital, n.d.)



Exercise

In one of the previous semesters, students were assigned to produce a greeting card shown below:



Figure 6.5.6:
“Greeting card”

Using simple tools like markers and plain A4 paper, they produced 54 batches of cards. The quality of their cards was examined in terms of the shape of the box, the position of the happy face, and the symmetry/size of the text. The following table summarizes the defects detected:

Sample number	Imperfect box	Face not centered	Big/skewed text
1	1	0	0
2	2	1	1
3	0	0	0
4	0	0	1
5	3	2	2
6	0	0	0
7	1	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	1	0
13	0	0	1
14	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	1
20	0	0	0
21	0	0	0
22	0	0	0
23	1	1	0
24	0	0	0
25	0	0	0
26	0	0	0

27	0	0	0
28	0	1	0
29	2	0	0
30	0	0	0
31	0	0	0
32	0	0	0
33	0	0	0
34	0	0	0
35	0	0	0
36	0	0	0
37	1	0	1
38	0	0	0
39	0	0	0
40	1	0	0
41	0	0	0
42	1	0	0
43	0	0	0
44	0	0	0
45	0	0	0
46	0	0	2
47	0	0	0
48	0	0	0
49	0	0	0
50	0	0	0
51	0	0	0
52	0	0	0
53	0	0	2

54	0	0	0
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Based on the above data, create a check sheet, a Pareto Chart for the defects, and a control chart and determine how the students' production quality with respect to each variable (Box, Face, Text) changed over time.

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6.6 CHAPTER SUMMARY & REVIEW



Summary

Chapter 6, “Managing Quality,” delves into the critical aspects of ensuring quality in products and services. It begins by defining quality from the consumer’s perspective, emphasizing that a product’s success hinges on meeting or exceeding customer expectations. This chapter highlights the historical shift towards quality in operations management, particularly noting how Japanese manufacturers set high standards that North American companies had to catch up with. It distinguishes between design quality, which focuses on the product’s inherent characteristics, and process quality, which ensures that manufacturing processes consistently produce defect-free products.

The chapter also introduces several key figures in the field of quality management, known as the quality gurus. These include Walter Shewhart, who pioneered statistical quality control; W. Edwards Deming, whose principles transformed Japanese manufacturing; Joseph Juran, known for the Juran Trilogy; Philip Crosby, an advocate for “zero defects”; and Armand Feigenbaum, who developed the concept of total quality management (TQM). Each guru’s contributions helped shape modern quality management practices, emphasizing continuous improvement, customer satisfaction, and employee involvement.

Moreover, the chapter outlines various quality systems and methodologies such as TQM, ISO standards, and Six Sigma. It discusses the costs associated with maintaining quality, categorized into prevention, appraisal, internal failure, and external failure costs. Additionally, it describes quality improvement tools like check sheets, histograms, Pareto charts, scatter diagrams, cause and effect diagrams, and control charts. By implementing these tools and adhering to established quality frameworks, organizations can

effectively monitor, control, and enhance their processes, ultimately leading to higher customer satisfaction and operational efficiency.

OpenAI. (2024, June 13). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than three paragraphs. Reviewed by authors.*



Review Questions

1. How do design quality and process quality differ, and why are both essential for achieving high product quality?
2. Discuss how consumer perceptions of quality can impact a company's success. Provide examples of how companies can bridge the gap between consumer expectations and product performance.
3. Explain the historical context that led North American companies to improve their quality standards. How did Japanese manufacturing practices influence this shift?
4. Compare and contrast the contributions of W. Edwards Deming and Joseph Juran to the field of quality management. How did their philosophies and methodologies shape modern quality practices?
5. Define and differentiate between prevention costs, appraisal costs, internal failure costs, and external failure costs. How can understanding these costs help a company manage its overall quality?
6. Describe the key principles of Total Quality Management (TQM). How do customer satisfaction, employee involvement, and continuous improvement contribute to TQM?
7. What are ISO standards, and why are they important for businesses? Discuss the steps involved in obtaining ISO certification and the benefits it can bring to an organization.
8. Explain the Six Sigma methodology and its DMAIC improvement model. How does Six Sigma help organizations reduce defects and improve quality?
9. Select two quality improvement tools (e.g., Pareto charts, control charts) and discuss how they are used in practice. Provide examples of how these tools can identify and solve quality issues.
10. Consider a product or service you are familiar with. Discuss how the principles and tools of quality management could be applied to improve its quality. What steps would you take to implement these improvements?

OpenAI. (2024, June 13). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create ten discussion questions based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

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6.7 KEY TERMS



Key Terms

- **Appraisal costs** refer to the resources dedicated to inspecting, testing, and evaluating products or services during the production or delivery process.
- **Assignable Variation** arises from identifiable and addressable causes, such as employee error, software malfunction, or equipment failure.
- **Black Belt:** A Black Belt is a full-time position within the quality department, where the individual works exclusively as a coach and leader for Six Sigma projects.
- **C-chart**, or count chart, monitors the number of defects or non-conformities in a sample or subgroup of constant size.
- **Cause-and-effect Diagrams**, also known as Fishbone diagrams, were developed by Dr. Kaoru Ishikawa to help identify the root causes of a problem. The diagram's overall shape resembles a fish's, with the "head" pointing to the effect or problem being analyzed. Each "rib" of the fishbone represents a major cause or category that could potentially contribute to the problem.
- **Champion:** A Champion is typically a senior manager or executive overseeing the Six Sigma program and its associated personnel.
- **Check Sheet** is a custom-designed form used to record the frequency or number of occurrences of a particular event or outcome of interest.
- **Common causes**, also known as chance causes or noise, are the natural and random fluctuations inherent in a stable and predictable process.
- **Common Variation**, also known as chance variation, is inherent to the process and generally expected.

- **Control Chart** is a statistical tool used to monitor and control the quality of a product or process. It is a graphical representation that depicts whether sample quality falls within the normal range of variation.
- **Cost of Quality**, a framework for understanding and managing the financial implications of quality.
- **Deming Cycle** or Deming Wheel is also known as PDCA, or “Plan, Do Check, Act.” It is a version of continuous improvement that emphasizes the continuous nature of process improvement.
- **DMAIC Improvement Model** stands for Define, Measure, Analyze, Improve, and Control. Six Sigma’s improvement method utilizes project teams to define problems, measure performance, analyze root causes, implement solutions, and establish controls for sustained improvement.
- **External failure costs** are incurred when defective products or non-conforming services reach the customer.
- **Green Belt:** A Green Belt designation indicates that an individual has received Six Sigma training.
- **HACCP** is a quality management system specifically designed for organizations in the food processing industry.
- **Hidden Plant**, refers to the untapped productive capacity lost due to inefficiencies, defects, and rework.
- **Histogram** is a graphical representation that displays the distribution of a dataset by grouping the data into bins or intervals along the horizontal axis and showing the frequency or count of observations in each bin on the vertical axis.
- **Internal failure costs** arise when defects or non-conformities are detected within the organization before the product or service is delivered to the customer.
- **Master Black Belt:** A Master Black Belt is a full-time position within the Six Sigma team, with extensive experience managing and overseeing Six Sigma projects.
- **Mean ($\bar{X}$) Chart:** This chart monitors the process mean or average value of the quality characteristic.
- **np-chart** monitors the number of defective items or units in a sample or subgroup of constant size.

- **P-charts**, or fraction defective charts, are useful when the quality characteristic cannot be quantified, such as holes in cloth or the absence of picture quality.
- **Pareto Chart** is a specialized type of bar chart that displays the frequency of occurrences for various characteristics, arranged in descending order from highest to lowest.
- **Pareto Principle**, also known as the 80/20 rule. This principle, originally an observation by Pareto that 80% of Italy's land was owned by 20% of the population, has become a cornerstone of problem-solving and continuous improvement efforts in quality management. The principle suggests that a significant portion of problems (around 80%) often stem from a relatively small number of root causes (around 20%).
- **Prevention costs** encompass all expenditures aimed at proactively avoiding the occurrence of defects or non-conformities in products or services.
- **Process Quality** refers to the ability of the organization to produce the good or service having perfect quality at each stage of the process, or in other words, manufacturing defect-free products.
- **Range (R) Chart:** This chart monitors the range or the difference between the highest and lowest values within a sample or subgroup.
- **Scatter Diagram** is a graphical representation that displays the relationship between two variables by plotting their values as a series of points on a Cartesian coordinate system.
- **Six Sigma** is a comprehensive set of techniques and tools designed for process improvement.
- **Special causes**, also known as assignable causes or signals, are abnormal and non-random fluctuations due to external factors.
- **Standard Deviation (σ) Chart:** This chart monitors the process variability by tracking the standard deviation of the quality characteristic.
- **The International Organization for Standardization (ISO)** is an independent, non-governmental organization that develops and publishes voluntary international standards.
- **Total Quality Management (TQM)**, also known as quality assurance, encompasses all the steps a company takes to ensure its products or services align

with customer-defined specifications and maintain high quality.

- **Zero Defects** is a philosophy emphasizing the elimination of errors from the outset.

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CHAPTER 7: SUPPLY CHAIN MANAGEMENT

Chapter Overview

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7.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Explain the fundamental concepts of supply chain management and its significance in fulfilling customer demands efficiently.
- Explain the material/goods flow, cash flow, and information flow within a supply chain and discuss their significance in maintaining efficient operations.
- Identify and explain the four key elements of supply chain management: supply management, internal operations management, distribution management, and integration management.
- Analyze different supply chain design strategies and assess how companies balance efficiency and responsiveness based on customer needs.
- Evaluate various inventory management practices and justify the reasons for maintaining different types of inventory within a supply chain.
- Compare different modes of transportation and discuss how companies choose the most appropriate mode for various types of shipments.
- Explain the role of technologies such as EDI, barcodes, QR systems, and RFID in enhancing supply chain operations and improving data capture and inventory management.
- Discuss collaborative practices like Vendor Managed Inventory (VMI) and Collaborative Planning Forecasting and Replenishment (CPFR) and their benefits for optimizing supply chain performance.
- Identify and explain the elements of socially responsible supply chain management by embracing ethically, socially, and environmentally sustainable

practices along with economic gain.

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7.1 INTRODUCTION

Supply Chain: A Collaborative Network

Supply chain refers to the interconnected network of organizations involved in fulfilling a customer order, from sourcing raw materials to delivering the final product. In contemporary marketplaces, customers demand quality goods and services, but not at high prices, and optimal customer service before and after they buy those products or services. They do not care how all this would be done for them, but on the other side of the spectrum, there are people with resources (goods, services, information, capital, etc.) that must be converted to the goods and services demanded in the market.

To make this possible, many participating operations would get involved, each connected with and adding value to the previous operations. The following figure shows that the elements linking these operations are people, processes and technology.

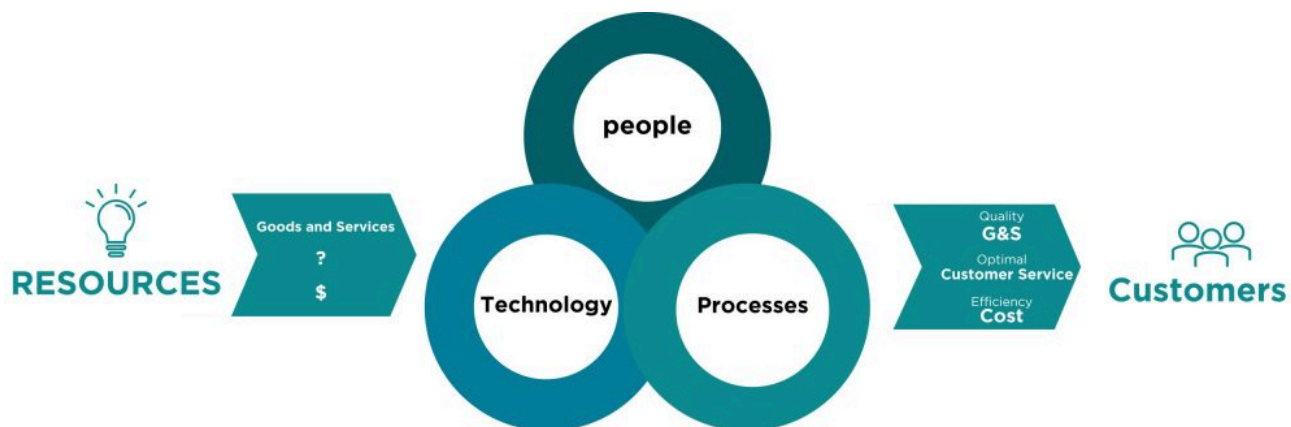


Figure 7.1.1 “Supply Chain Network” by Sanaz Habibi, [CC BY-NC-SA 4.0](https://creativecommons.org/licenses/by-nc-sa/4.0/)

Each participant plays a crucial role in adding value for the end consumer. The supply chain encompasses suppliers, manufacturers, transporters, distribution centers, wholesalers, retailers, and end-consumers. Consider them as loops in a chain; if one operation does not add value to the previous one or does not support the next one, the chain will break.

The Strength of the Chain

The effectiveness of a supply chain is determined by its weakest link. This principle underscores the importance of supply chain management, which extends beyond a company’s internal operations.

Organizations must actively collaborate with their supply chain partners to ensure optimal performance at every stage.

Ripple Effect of Inefficiencies

A weakness in any link of the supply chain can have far-reaching consequences. For instance, if a retailer fails to replenish inventory promptly, it can lead to product unavailability for end consumers, resulting in lost sales. This ripple effect propagates upstream, with fewer orders placed with manufacturers and, consequently, reduced demand for raw materials from suppliers. Ultimately, the entire supply chain suffers financial implications due to a single weak link.

Collaborative Optimization

To mitigate such risks and maximize efficiency, organizations must adopt a collaborative approach to supply chain management. Regular communication and coordination with supply chain partners are essential to identify and address potential bottlenecks proactively. By fostering a culture of continuous improvement and leveraging advanced technologies, companies can optimize their supply chain operations, ensuring the timely delivery of products and services while minimizing waste and maximizing customer satisfaction.

For example, if a retail store is not doing a good job at replenishing its 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 been 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 sells less than they could if the retailer ordered the right quantity at the right time.

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7.2 MANAGING MAIN FLOWS IN THE SUPPLY CHAIN

Supply chains are governed by three fundamental flows: the flow of materials/goods, the flow of money/cash, and the flow of information. These flows are intrinsically linked and essential for the efficient operation of any supply chain.

Material/Goods Flow

The **material/goods flow** represents the physical movement of products along the supply chain. It typically follows a forward direction, originating from higher-tier suppliers (upstream) and progressing toward the end consumer (downstream). However, in returns or reverse logistics cases, a reverse flow of materials/goods occurs in the opposite direction.

Cash Flow

The **cash flow**, or the flow of money, moves in the opposite direction to the material/goods flow. It originates from downstream entities, such as retailers, who pay distributors or manufacturers for the goods received. This flow continues upstream, with each participant in the supply chain receiving payment for their contributions.

Information Flow

The flow of information is bidirectional, enabling effective communication and coordination among supply chain partners. Organizations share various types of information, including demand forecasts, inventory levels, production schedules, and logistics data. This exchange of information facilitates better decision-making and optimizes the overall performance of the supply chain.

Synchronization and Optimization

Effective supply chain management requires the seamless integration and synchronization of these three flows. By aligning the material/goods flow with the cash flow and leveraging the flow of information, organizations can streamline operations, reduce waste, and enhance customer satisfaction. Advanced

technologies and collaborative practices enable real-time monitoring and optimization of these flows, driving efficiency and competitiveness within the supply chain.

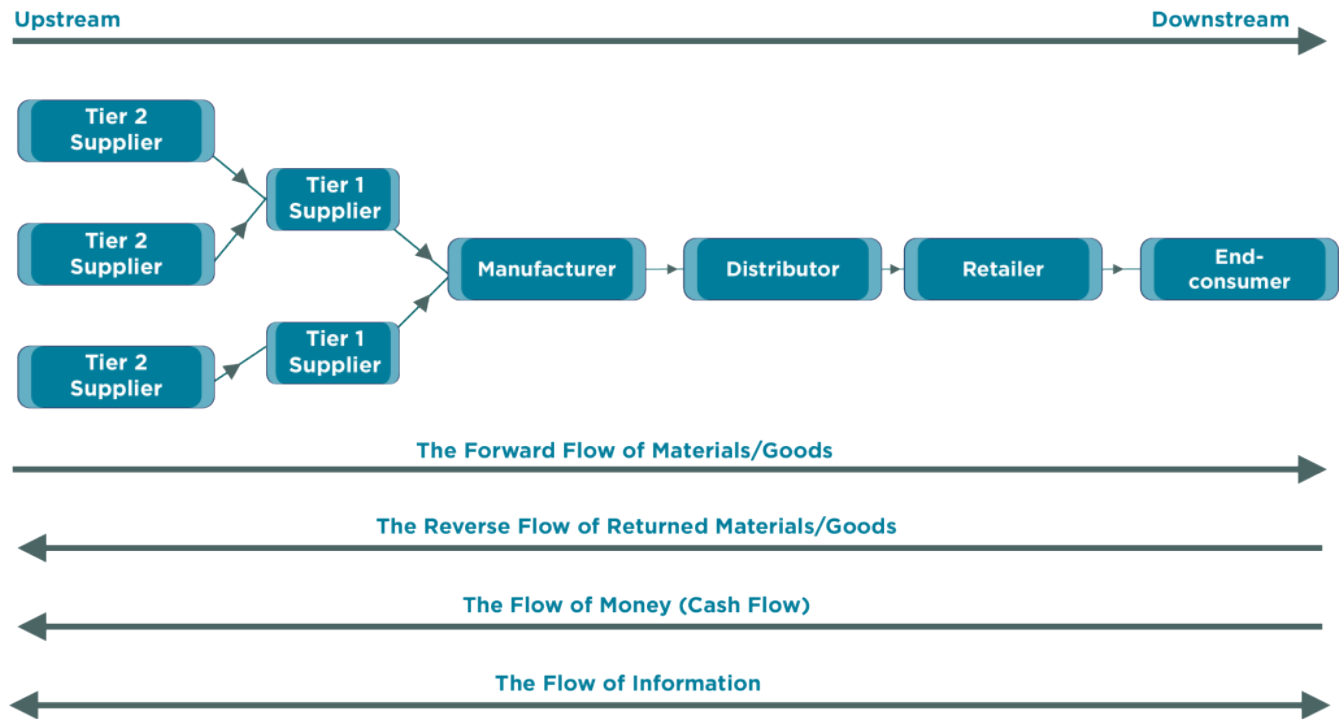


Figure 7.2.1: Upstream and downstream of a supply chain and its flows. Mods: recoloured by Fanshawe College

Image Description

This diagram illustrates the various stages and flows within a supply chain, highlighting the upstream and downstream activities. The diagram is organized as follows:

1. Upstream (on the left side of the diagram):
 - Tier 2 Suppliers: There are three boxes labelled “Tier 2 Supplier,” indicating the suppliers that provide raw materials or components to the Tier 1 suppliers.
 - Tier 1 Suppliers: Two boxes labelled “Tier 1 Supplier” receive inputs from Tier 2 Suppliers and pass their outputs to the manufacturer.
2. Downstream (on the right side of the diagram):
 - Manufacturer: The manufacturer receives components from Tier 1 Suppliers, processes them, and forwards the products to the distributor.
 - Distributor: The distributor receives products from the manufacturer and distributes them to

retailers.

- Retailer: The retailer receives products from the distributor and sells them to the end-consumer.
- End-consumer: The final recipient of the product in the supply chain.

3. Flow Descriptions:

- The Forward Flow of Materials/Goods: An arrow at the top indicates the movement of materials and goods from upstream to downstream.
- The Reverse Flow of Returned Materials/Goods: An arrow below the forward flow indicates the movement of returned goods from the end-consumer back up the supply chain.
- The Flow of Money (Cash Flow): An arrow indicates the flow of money in the opposite direction, from the end-consumer to the upstream suppliers.
- The Flow of Information: An arrow at the bottom indicates the bidirectional flow of information throughout the supply chain.

Video: “[What is Supply Chain Management? Definition, Introduction, Process & Examples | AIMS UK](#)” by [AIMS Education, UK](#) [12:07] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

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7.3 FOUNDATIONAL ELEMENTS OF SUPPLY CHAIN MANAGEMENT

For organizations within a supply chain, effective management hinges on four key elements: supply management, internal operations management, distribution management, and integration management. These elements form the foundational pillars that enable harmonious collaboration among all participants in the supply chain. Figure 7.3.1 illustrates the interplay of these elements within a company's supply chain.

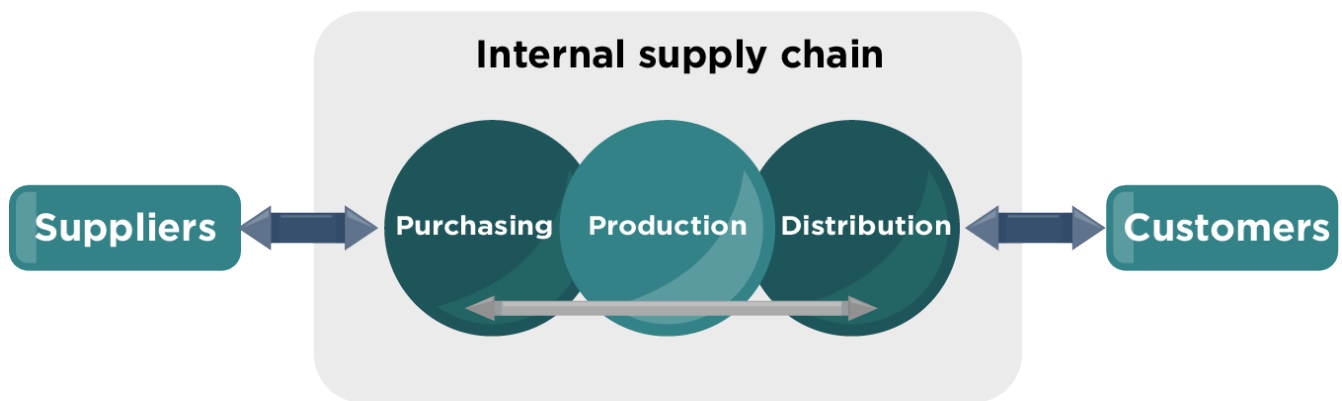


Figure 7.3.1: “A company's supply chain” by Stern, CC BY-SA 3.0. Mods: re-coloured by Fanshawe College. The internal supply chain starts with suppliers providing the raw materials purchased, manufactured into goods and distributed to the customers.

Supply Management

Supply management encompasses the procurement and management of suppliers and the cultivation of strong relationships with them. This element involves activities such as supplier selection, contract negotiation, and performance monitoring to ensure a reliable and efficient flow of materials or services.

Internal Operations Management

Internal operations management focuses on the processes and activities through which a company adds value to its products or services. For a manufacturer, this may include production planning, inventory management (both raw materials and finished goods), human resource management, and quality control processes.

Distribution Management

Distribution management involves managing customer relationships and developing a deep understanding of their needs and preferences. This element ensures that the right products or services are delivered to the right customers at the right time, fostering customer satisfaction and loyalty.

Integration Management

Integration management serves as the glue that binds the other elements together. It leverages technologies such as Enterprise Resource Planning (ERP) systems to facilitate seamless collaboration and information sharing among the various components of the supply chain. This integration enables accurate and efficient coordination, enhancing overall supply chain performance.

By effectively managing these four foundational elements, organizations can optimize their supply chain operations, reduce waste, and enhance customer satisfaction. Successful supply chain management requires a holistic approach, where each element is carefully orchestrated to support the overarching goals of the supply chain network.

Video: “[Module 6: Supply Chain Integration – ASU’s W. P. Carey School](#)” by [W. P. Carey School of Business](#) [4:40] is licensed under the [Standard YouTube License](#).
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7.4 SUPPLY CHAIN DESIGN

Supply chain design is a strategic decision that determines various entities' roles, responsibilities, and geographical locations within the supply chain network. Companies adopt different supply chain structures to align with their business objectives and customer preferences. For instance, Walmart traditionally relied on brick-and-mortar stores to serve customers, while Amazon has leveraged an online platform to direct shipments from distribution centers.

Balancing Efficiency and Responsiveness

When designing a supply chain, two critical factors must be considered: efficiency (cost reduction) and responsiveness. The balance between these two factors varies across companies, depending on customer preferences. If customers are willing to wait 5-7 days for online orders, a company can consolidate inventory in fewer locations and leverage longer transportation times. However, if customers demand immediate product availability, the company may need to establish multiple retail locations and maintain sufficient inventory at each site to respond promptly to customer needs.

Vertical and Horizontal Integration

Companies can choose to outsource certain supply chain functions or maintain control over various stages through vertical and horizontal integration strategies.

- **Vertical Integration:** Vertical integration occurs when a firm owns more than one portion of its supply chain. For a manufacturer, this could involve owning distributors or retail stores for forward integration (reaching end-consumers directly) or acquiring suppliers for backward integration (controlling the sourcing of materials or components).
- **Horizontal Integration:** Horizontal integration involves a business expanding its holdings by acquiring or merging with another firm operating in the same market. Examples include the 2015 merger of Kraft Foods and Heinz, and Marriott International's acquisition of Starwood Hotels in 2016.

Tailoring the Supply Chain Design

By carefully designing their supply chain structure, companies can optimize operational efficiency, enhance responsiveness, and align with customer expectations. This strategic decision involves evaluating factors such

as product characteristics, market dynamics, and competitive landscape, ultimately shaping supply chain entities' roles, responsibilities, and locations to achieve a competitive advantage.



Examples

Ford's Vertical Integration Strategy

In the early 20th century, Ford Motor Company embarked on a strategic vertical integration approach surrounding its Highland Park Plant. This complex included a power plant, machine shop, and foundry, enabling Ford to consolidate various stages of automobile manufacturing under its control.

By the 1920s, Ford had acquired a rubber plantation in Brazil, coal mines in Kentucky, timberlands and iron-ore mines in Michigan and Minnesota, a fleet of ships, and a railroad. These efforts aimed at vertical integration ensured a reliable supply of raw materials and parts, guaranteeing a continuously operating assembly line.

Ford's vertical integration strategy secured the necessary resources for production and enabled the company to profit from multiple processes involved in automobile manufacturing. This approach gave Ford greater control over its supply chain, reducing dependencies and enhancing operational efficiency (Parkhani, 2019; Stanford, n.d.).



[“Fordlandia-Brazil”](#), Amit Evron, [CC BY-SA 3.0](#)

Netflix's Backward Vertical Integration

Netflix exemplifies a significant backward vertical integration strategy in the entertainment industry. Initially, Netflix operated at the end of the supply chain as a platform for distributing films and TV shows created by other content creators.

While this business model was profitable, Netflix's leaders recognized the potential for greater revenue generation by creating their own original content. This strategic move would reduce their reliance on external content creators and cater to the growing demand among subscribers for original programming.

By leveraging their existing distribution platform, Netflix could effectively promote and deliver their original content to a captive audience. This backward vertical integration strategy has become crucial for Netflix's continued success as more film studios terminate their licensing agreements with the streaming giant. The company's original content has become a primary attractor for new subscribers, solidifying its highly competitive entertainment industry position.

Both examples illustrate how vertical integration strategies, whether forward or backward, can provide companies with greater control over their supply chains, secure access to critical resources, and create opportunities for revenue diversification and growth (Quain, 2018).



"Netflix TV" by [Stock Catalog & Quote Catalog](#), CC BY 2.0

7.5 THE ROLE OF INVENTORY IN THE SUPPLY CHAIN

Inventory management is a critical activity within the supply chain, ensuring that materials and goods are available in the right quantities, at the right locations, and at the right time. Without proper inventory management, producing high-quality goods and meeting customer commitments is impossible.

Types of Inventories in the Supply Chain

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

Reasons for Holding Inventories

There are several reasons why organizations maintain inventory stocks:

1. *Seasonal Demand:* Manufacturers often build up inventories throughout the year to meet seasonal demand fluctuations. For example, a chocolate manufacturer may begin stockpiling inventory in late spring to fulfill the high demand during the Christmas season.
2. *Supply Chain Risks:* Companies may carry larger inventories to mitigate risks associated with their supply base, such as shortages, work stoppages, poor quality, or late deliveries from suppliers.
3. *Cost Optimization:* Organizations may be incentivized to purchase larger order quantities to take advantage of discounts or minimize transportation costs. Additionally, concerns about future price increases can prompt companies to build up their inventories.
4. *Customer Service:* Retailers carry inventory to ensure they can meet customer demand without running out of stock. Distributors and retailers strive to balance the cost of maintaining large inventories with providing excellent customer service and minimizing disappointed customers.

5. *Supply Chain Synchronization*: Aligning the incoming flow of materials and goods with production schedules and customer shipments can be challenging. As a result, inventory may be stored at various locations along the supply chain, leading to additional costs and inefficiencies.

Effective inventory management is crucial for supply chain optimization. It involves balancing between maintaining sufficient stock levels to meet customer demand and minimizing the costs associated with carrying excess inventory. Advanced techniques, such as demand forecasting, inventory optimization, and supply chain visibility, can help organizations achieve this delicate balance and enhance overall supply chain performance.

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7.6 LOGISTICS: COORDINATING THE MOVEMENT OF RESOURCES

Logistics refers to the coordination and movement of resources, particularly inputs into the transformation process and finished goods out to customers. Originally derived from military operations, logistics involves managing the flow of troops, equipment, and supplies. In a business context, logistics management encompasses the following decisions:

1. Determining whether to operate and manage the firm's transportation activities in-house or outsource them.
2. Selecting suppliers with the capability to ship goods safely and securely within the required time frame.
3. Choosing the appropriate mode of transportation and the most effective route.
4. Negotiating shipping rates.

Modes of Transportation

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

Trucking: The Backbone of Freight Transportation

Trucking plays a pivotal role in the movement of goods, with the majority of shipments relying on trucks either entirely or at some point during the transportation process. Trucking stands out as the most flexible mode of transportation, offering two primary categories:

1. **Truck-Load (TL):** In this category, an entire truck is hired and dedicated to a single shipment, ensuring direct delivery from origin to destination.
2. **Less-than-Truckload (LTL):** This approach involves consolidating multiple orders onto a single truck, thereby increasing the utilization of the vehicle and optimizing transportation costs.

Overcoming the driver shortage is crucial for maintaining the efficiency and reliability of the trucking sector, which serves as the backbone of freight transportation. By addressing this challenge proactively, the industry can ensure its continued ability to meet the ever-growing demand for timely and flexible goods movement, supporting the overall supply chain and economic growth.

Rail Transportation: Efficient Long-Haul Logistics

Rail offers a cost-effective solution for transporting containerized, bulky, and heavy goods over long distances. In Canada, rail plays a vital role in shipping diverse commodities like automobiles, fertilizers, food, forest products, grains, metals, minerals, and petroleum products.

Key advantages of rail include:

- Suitability for large-scale shipments, prompting manufacturers to locate near rail lines for efficient logistics.
- High energy efficiency compared to trucking, reducing environmental impact and highway congestion.
- Canada's well-established, extensive rail infrastructure supports nationwide cargo movement.

By leveraging rail's ability to move large volumes cost-effectively over long hauls, businesses can optimize supply chains, reduce transportation costs, and enhance sustainability. Rail's integration with other modes enables multimodal logistics solutions, boosting efficiency and flexibility in goods movement.

Airfreight: Rapid Transit for High-Value Cargo

Airfreight is the preferred mode for expensive, small, and lightweight goods where speed takes precedence over cost. Air carriers charge based on weight and dimensions, suiting high-value, time-sensitive shipments.

Key advantages:

- Unparalleled speed and reliability for rapid long-distance transport
- Beneficial for industries prioritizing timely delivery, like electronics and pharmaceuticals

Considerations:

- Higher environmental impact due to greenhouse gas emissions
- Firms should explore strategies like shipment consolidation, carbon offsetting, or alternative modes for non-urgent shipments

By balancing speed requirements with environmental concerns, businesses can leverage airfreight judiciously for high-value, time-critical cargo while promoting sustainable logistics practices.

Waterway Transportation: Cost-Effective for Bulk Shipments

Waterways are a common mode for shipping heavy commodities like chemicals, stone, cement, sugar, coal, and other bulk materials. Millions of containers travel by ship annually.

Key advantages:

- Cost-effectiveness, especially for low-cost, bulk products.
- Major systems like the Great Lakes St. Lawrence Seaway, a 3,700-kilometer marine highway opened in 1959, facilitate trade between Canada and the U.S., serving many industries to ship iron ore, coal, limestone, steel, grain and cement (The St. Lawrence Seaway Management Corporation, n.d.).
- Reduces road congestion and environmental impact by diverting freight from highways.

Waterway transportation offers an efficient and economical logistics solution for industries relying on bulk commodity movement or low-cost product shipments.

As global trade grows, the importance of waterways in optimizing supply chain costs and reducing environmental footprint remains significant.



[Do you know what goods are transported through the ship?](#)

Pipeline Transportation

Pipelines are the primary mode of transportation for crude oil, natural gas, and other petroleum products. Once the pipeline infrastructure is established, the cost per kilometre for shipping these commodities is relatively inexpensive.

However, the construction of new pipelines often faces significant opposition and concerns due to the potential risks of spills and leaks, which can lead to land and water contamination, posing environmental threats.

Multimodal/Intermodal Shipping: Integrated Logistics Efficiency

Multimodal and intermodal shipping leverage multiple transportation modes (e.g., truck/ship/rail) to move goods efficiently from origin to destination under a single contract. Intermodal shipping utilizes containers, minimizing handling during mode transfers.

Key benefits:

- Increased security and reduced loss/damage
- Enhanced speed through streamlined mode transfers
- Optimized efficiency by utilizing the strengths of each mode

With designated carriers responsible for each leg, these integrated solutions enable coordinated, accountable, and seamless logistics operations.

Multimodal/intermodal shipping combines various modes and provides businesses with flexible and efficient supply chain solutions for optimizing goods movement across diverse regions.



Figure 7.6.1: Diagram summarizing various modes of transportation.

Distribution Management: Orchestrating Efficient Product Flow

Distribution management refers to the process of overseeing the movement of goods from suppliers or manufacturers to the point of sale. It is a critical component of the business cycle for distributors and wholesalers, as their profitability hinges on the ability to rapidly turn over their inventory. The faster goods are sold, the higher the earnings, ensuring the business's future growth and success. Effective distribution management is essential for businesses to remain competitive and maintain customer satisfaction.

Distribution encompasses a diverse range of functions, including customer service, shipping, warehousing, inventory control, private trucking fleet operations, packaging, receiving, and materials handling, as well as strategic planning for plant, warehouse, and store locations. Additionally, the integration of information systems plays a crucial role in streamlining distribution processes.

The overarching goal of distribution management is to achieve ultimate efficiency in delivering raw materials, parts, and both partially and completely finished products to the right place, at the right time, and in the proper condition (Kenton, 2019).

The combination of distribution and transportation forms the backbone of logistics operations. In any logistics system, the most critical factor is the ability to deliver products quickly while maintaining their perfect condition. Companies like Amazon have leveraged their supply chain management expertise to fuel their rise to the top, demonstrating the importance of efficient distribution in achieving business success.

By effectively managing distribution processes, businesses can optimize inventory levels, reduce costs, and enhance customer satisfaction, ultimately driving profitability and competitiveness in their respective markets.

The combination of distribution and transportation is logistics. The most important factor in any logistics is quickly delivering the product in perfect condition.



[How Amazon has used its supply chain management to fuel its rise to the top](#)

Cross-docking: Streamlining Product Flow

Cross-docking involves transferring goods directly from inbound to outbound carriers, bypassing warehousing and storage. Products “cross the docks” from receiving to shipping areas.

Key benefits:

- Inventory savings by eliminating storage costs
- Accelerated delivery for improved customer service
- Reduced handling and risk of damage
- Optimized space utilization

Cross-docking streamlines supply chains by minimizing product movement time and resources is ideal for time-sensitive, perishable, or high-turnover goods.

Effective implementation requires synchronizing inbound/outbound shipments, collaborating with partners, and leveraging technologies like real-time tracking.

Through cross-docking, businesses can optimize operations, reduce inventory costs, and enhance timely, cost-effective product delivery for a competitive advantage.

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7.7 COMMUNICATION AND TECHNOLOGY IN THE SUPPLY CHAIN

Electronic Data Interchange (EDI): Enabling Seamless Business Communication

Electronic Data Interchange (EDI) is a computer-to-computer exchange of business documents, such as purchase orders and invoices, in a standardized electronic format between business partners. This technology facilitates the automated transfer of documents between organizations, eliminating the need for manual intervention.

EDI enables companies to seamlessly exchange critical business information, such as purchase orders, invoices, advance shipment notices, customs documents, inventory data, shipping status, payment documents, bills of lading, and sales/price catalogues.

The primary advantages of EDI include: (EDI Resource Center, n.d.)

1. *Speed and accuracy:* Information is transmitted in real-time, minimizing delays and eliminating errors that may occur during manual data entry processes.
2. *Automation:* By automating document exchange, EDI reduces the need for human intervention, streamlining business processes and improving operational efficiency.
3. *Cost savings:* Eliminating manual data entry and associated errors can lead to significant cost savings for businesses.
4. *Improved collaboration:* EDI enhances collaboration and communication between business partners by providing a standardized and secure platform for information exchange.
5. *Compliance and traceability:* EDI systems often incorporate robust security measures and audit trails, ensuring compliance with regulatory requirements and enabling traceability of transactions.

EDI plays a crucial role in supply chain integration in operations management, enabling seamless communication and coordination among suppliers, manufacturers, distributors, and retailers. By facilitating the real-time exchange of critical business documents, EDI supports efficient inventory management, production planning, and logistics operations, ultimately improving supply chain performance and customer satisfaction.

As businesses continue to embrace digital transformation and seek to optimize their operations, adopting EDI becomes increasingly important, enabling organizations to streamline their processes, enhance collaboration, and gain a competitive edge in the marketplace.

Barcodes: Enabling Efficient Data Capture

Barcodes, widely adopted since the 1970s, display machine-readable data that can be scanned by barcode readers, containing information like pricing, product numbers, and descriptions.

Key advantages in retail operations:

- Accurate pricing and easy price changes
- Real-time inventory tracking and updates
- Identification of fast/slow-moving products for forecasting

Benefits across industries:

- Eliminates manual data entry errors
- Streamlines processes like inventory management and checkout
- Enables product traceability throughout the supply chain
- Supports inventory control and optimization
- Provides data for analysis and process improvements

Barcodes have become an integral part of modern supply chain and inventory management systems, driving operational efficiency, cost savings, and improved customer service through efficient data capture and tracking.

Quick Response (QR) Systems: Enabling Just-in-Time Retail Replenishment

QR systems leverage barcodes and EDI to provide vendors with real-time sales data for prompt replenishment of goods in the correct quantities – a just-in-time (JIT) approach for retail.

Key objectives:

- Reducing out-of-stock incidents through timely replenishment
- Optimizing inventory levels with smaller, frequent deliveries
- Enabling a responsive and agile supply chain
- Fostering retailer-vendor collaboration and coordination

Benefits include improved inventory management, reduced stockouts, lower operating costs, and better alignment of supply with demand.

As consumer expectations evolve, QR systems and JIT strategies become crucial for maintaining competitiveness and meeting customer demands effectively in the retail industry.

Radio Frequency Identification (RFID): Wireless Data Tracking

RFID utilizes radio waves to communicate data stored on tags attached to objects, such as product details, shipment information, and pricing. It requires a tag and reader, with active tags containing a power source for a longer range and passive tags relying on the reader's energy.

Key advantages over barcodes:

- No line-of-sight required for data transmission
- Enables flexible and efficient tracking processes

Applications across industries:

- Retail inventory management and theft prevention
- Shipping and asset tracking (tools, devices, luggage)
- Access control and identification (passports, toll payments)
- Race timing and event management

RFID technology streamlines operations, improves supply chain visibility, enhances security, and optimizes asset management through wireless data capture and real-time tracking capabilities.

As costs decrease, RFID adoption is expected to grow, enabling businesses to gain competitive advantages through improved data management and operational excellence.

“[7.7 Communication and Technology in the Supply Chain](#)” from [Fundamentals of Operations Management](#) by Azim Abbas and Seyed Goosheh is licensed under a [Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License](#), except where otherwise noted.

7.8 SUPPLY CHAIN COLLABORATION

Vendor Managed Inventory (VMI)

VMI is an advanced supply chain relationship where a vendor manages and maintains agreed inventory levels at the customer's location, leveraging access to real-time inventory data.

Key benefits

For vendors:

- Motivation to ensure fully stocked shelves and to discontinue slow movers
- Opportunity for comprehensive product training and support
- Improved inventory visibility and demand forecasting

For customers:

- Reduced workload in inventory management
- Fewer errors and faster goods flow through EDI integration
- Automated replenishment based on point-of-sale data
- Access to vendor expertise and on-site support

VMI fosters closer vendor-customer collaboration, enabling optimized inventory levels, reduced stockouts, and enhanced supply chain efficiency.

Successful implementation requires trust, transparency, effective communication, and robust information sharing between partners.

VMI represents a strategic approach to collaborative inventory management and operational excellence across the supply chain.

Collaborative Planning, Forecasting, and Replenishment

(CPFR): Aligning Supply Chain Partners

CPFR enables trading partners (manufacturer and distributor/retailer) to collaborate on forecasting and order planning by:

- Sharing point-of-sale data, promotion plans, inventory status, and forecasts.
- Comparing shared data with the manufacturer's forecasts and capacity.
- Collaboratively resolving discrepancies and agreeing on final forecasts/replenishment plans.

Key benefits

- Inventory optimization and reduced stockouts
- Improved demand visibility for better production planning
- Proactive problem-solving for potential issues
- Strengthened partner relationships and trust

Effective CPFR implementation requires commitment, trust, information sharing, and robust technology platforms between partners.

By aligning forecasts and replenishment strategies, CPFR helps optimize operations, reduce costs, and enhance customer service levels across the supply chain.

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 reduce problems such as shortages and capacity problems.

Measuring Supply Chain Performance

Video: “[How to Measure Supply Chain Performance](#)” by [Skillsoft YouTube](#) [3:11] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Inventory Turnover: A Key Performance Indicator for Supply Chain Efficiency

Key Performance Indicators are measurements used to evaluate supply chain performance. One of the ways to evaluate the supply Key Performance Indicators (KPIs) are essential measurements used to evaluate supply chain performance. One crucial KPI is inventory turnover, which is calculated using the following formula:

$$\text{Inventory Turnover} = \frac{\text{Cost of Goods Sold}}{\text{Average Aggregate Inventory Value}}$$

The “**average aggregate inventory value**” refers to the total inventory held in stock, including raw materials, work-in-process, and finished goods, valued at cost.

Inventory turnover indicates an organization’s policies and practices, reflecting its ability to purchase materials, produce, and sell products in a timely manner. A higher inventory turnover value signifies that the organization has more effectively replenished and sold its inventory within a given period, resulting in better cash flow.

It is important to note that the interpretation of high or low inventory turnover values is relative to the specific industry. For example, the dairy (milk) manufacturing industry typically has an annual inventory turnover of around 23, while grocery supermarkets have a turnover of 14.7, and the automotive industry has a turnover of 4.8. Industries with higher volume and lower margins generally have the highest inventory turnover.

Analyzing inventory turnover provides valuable insights into supply chain efficiency and inventory management practices. A high turnover rate may indicate effective inventory management and a well-

optimized supply chain, while a low turnover rate could suggest potential issues such as overstocking, slow-moving inventory, or inefficient production processes.

By monitoring and optimizing inventory turnover, businesses can improve their cash flow, reduce carrying costs, and enhance overall supply chain performance. However, it is crucial to consider industry-specific factors and benchmarks when interpreting and setting targets for inventory turnover.



Example

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?

	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 = $17,550,000 \div 1,650,000 = 10.64$ turns

Inventory turns for two years ago = $16,255,000 \div 1,763,350 = 9.22$ 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:

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



Example

J's Custom Automotive Finishing has calculated that its annual cost of goods sold is 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

$$\text{Days of supply} = (3,025,600 \div 45,000,000) \times 365 = 24.54$$

This measure can be thought of as the amount of inventory sitting in the building at any one time. A lower number is better for measuring the efficiency of the inventory. This implies that goods are purchased more frequently and that less time is spent 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, the 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.

Socially Responsible Supply Chain Management: Embracing Ethical and Sustainable Practices

Socially responsible supply chain management encompasses a range of practices promoting ethical, environmentally conscious, and socially responsible operations throughout the supply chain.

The main areas of focus include:

- *Organizational practices:* Implementing policies and procedures that foster transparency, accountability, and good governance within the organization and its supply chain partners.
- *Ethical practices:* Adhering to ethical standards and codes of conduct that promote fair business practices, anti-corruption measures, and responsible sourcing of materials and components.
- *Environmental practices:* Adopting environmentally sustainable practices, such as reducing carbon footprint, minimizing waste, and promoting the use of renewable resources and energy-efficient processes throughout the supply chain.
- *Human rights and working conditions:* Ensuring that supply chain partners respect and uphold human rights, provide fair working conditions, and prohibit practices such as child labour, forced labour, and discrimination.
- *Occupational health and safety:* Prioritizing the health and safety of workers by implementing robust occupational health and safety measures, providing appropriate training, and ensuring compliance with relevant regulations.
- *Community engagement:* Establishing positive relationships with local communities by supporting community development initiatives, promoting local employment, and minimizing negative environmental and societal impacts.

By embracing socially responsible supply chain management practices, organizations can mitigate risks associated with unethical or unsustainable practices and contribute to the well-being of society and the environment. This approach can enhance brand reputation, foster customer loyalty, and attract socially conscious investors and stakeholders.

Implementing socially responsible supply chain management requires a comprehensive strategy, strong leadership commitment, and collaboration with supply chain partners. It involves setting clear goals, establishing monitoring and reporting mechanisms, and continuously improving practices to align with evolving social and environmental standards.

Video: “[Building A Sustainable \(Responsible\) Supply Chain Management System](#)” by [InterPraxis Sustainability](#) [6:23] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

The following table (Ciliberti et al., 2008) summarizes activities and practices considered good examples for the CSR areas listed above.

Relevant CSR Areas	Sample Practices
Organizational Practices	• Determining CSR goals for the purchasing function • Determining and defining the 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 the supplier selection process) • Not creating illegitimate pressures on suppliers • Not sharing price and service information about suppliers with other irrelevant stakeholders • Not favouring any particular supplier just because of managers' preferences and assuring a fair selection process • Assuring all departments meet ethical standards in the independent purchasing process • Not creating an 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 to reduce waste (especially hazardous waste) • Putting special emphasis on producing recyclable and reversible materials in production and design • Meeting standards for protecting the 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 the cycle, just because they have managers from different backgrounds • Having procedures and also having mechanisms to monitor and provide equal opportunity for each employee working in all supplier companies • Having appropriate procedures in place to ensure 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 ensure 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 ensure that sensitive and delicate products are stored under appropriate conditions
Practices to establish a relationship with society	• Developing and carrying out programs for the training and development of local suppliers • Actively participating in and organizing not-for-profit social activities, such as volunteer work, charities, public auctions, etc. • Supporting sports 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 the same requirements,

constitute the most important factors for CSR in supply chains. This issue is also important to stay competitive in the market and to have sustainable growth in terms of a strategic perspective.

Video: “[Business is about purpose: R. Edward Freeman at TEDxCharlottesville 2013](#)” by [TEDx Talks](#) [17:38] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

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7.9 CHAPTER SUMMARY & REVIEW



Summary

Chapter 7 focuses on the interconnected network of organizations involved in fulfilling customer orders, highlighting the collaborative nature of supply chains. It discusses the importance of each participant's role in adding value, from suppliers and manufacturers to retailers and end-consumers, and emphasizes that the chain's strength is determined by its weakest link. Inefficiencies at any stage can cause ripple effects throughout the supply chain, impacting the entire network's financial performance. To mitigate these risks, organizations must adopt collaborative optimization, involving regular communication and coordination with supply chain partners to identify and address potential bottlenecks proactively.

The chapter also explores the three main flows governing supply chains: materials/goods, cash, and information. The material/goods flow represents the physical movement of products, typically progressing from suppliers to end-consumers. The cash flow moves in the opposite direction, starting from downstream entities like retailers and moving upstream to suppliers. The information flow is bidirectional, enabling effective communication and coordination among supply chain partners. Synchronizing and optimizing these flows through advanced technologies and collaborative practices can drive efficiency, reduce waste, and enhance customer satisfaction. The chapter highlights key elements for effective supply chain management, including supply management, internal operations management, distribution management, and integration management, each playing a crucial role in optimizing operations and achieving supply chain goals.

Finally, the chapter delves into supply chain design, emphasizing the need to balance

efficiency and responsiveness based on customer preferences. It discusses vertical and horizontal integration strategies, such as Ford's vertical integration and Netflix's backward integration, demonstrating how companies can control various stages of their supply chains to secure resources and enhance operational efficiency. The role of inventory management is also addressed, highlighting the reasons for holding inventories and the importance of effective logistics and transportation modes in coordinating resource movement. Additionally, the chapter covers the impact of communication and technology, such as EDI, barcodes, QR systems, and RFID, in streamlining supply chain operations, enhancing data capture, and enabling just-in-time inventory management. Collaborative practices like Vendor Managed Inventory (VMI) and Collaborative Planning Forecasting and Replenishment (CPFR) are also discussed, illustrating the benefits of aligning supply chain partners to optimize performance and ensure customer satisfaction.

OpenAI. (2024, June 14). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than three paragraphs. Reviewed by authors.*



Review Questions

1. Explain the concept of a supply chain as a collaborative network. How does each participant in the supply chain add value to the final product?
2. Discuss the ripple effect of inefficiencies in the supply chain. Provide an example of how a delay at one stage can impact the entire supply chain.
3. What are the key elements of collaborative optimization in supply chain management? How can regular communication and coordination with supply chain partners improve overall efficiency?
4. Describe the three fundamental flows in the supply chain: material/goods flow, cash flow, and information flow. How do these flows interrelate to ensure efficient supply chain operations?
5. Discuss the strategic decisions involved in supply chain design. How do companies balance efficiency and responsiveness, and what factors influence these decisions?
6. Compare and contrast vertical and horizontal integration strategies in supply chain management. Provide examples from the chapter, such as Ford's vertical integration and Netflix's backward integration.
7. Why is inventory management critical in the supply chain? Discuss the different types of inventories and the reasons for holding them.
8. Explain the various modes of transportation discussed in the chapter (trucking, rail, airfreight, waterway, pipeline, and multimodal shipping). How do companies decide which mode to use for different types of shipments?
9. How do technologies like Electronic Data Interchange (EDI), barcodes, QR systems, and RFID enhance supply chain operations? Discuss their roles in improving data capture and inventory management.
10. What are Vendor Managed Inventory (VMI) and Collaborative Planning Forecasting and Replenishment (CPFR)? How do these collaborative practices benefit both suppliers and customers in the supply chain?

OpenAI. (2024, June 14). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create ten discussion questions based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

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7.10 KEY TERMS



Key Terms

- **Average aggregate inventory value** refers to the total inventory held in stock, including raw materials, work-in-process, and finished goods, valued at cost.
- **Barcodes**, widely adopted since the 1970s, display machine-readable data that can be scanned by barcode readers, containing information like pricing, product numbers, and descriptions.
- **Cash flow**, or the flow of money, moves in the opposite direction to the material/goods flow.
- **Collaborative Planning, Forecasting, and Replenishment (CPFR)**: enables trading partners (manufacturer and distributor/retailer) to collaborate on forecasting and order planning.
- **Cross-docking** involves transferring goods directly from inbound to outbound carriers, bypassing warehousing and storage.
- **Distribution management** refers to the process of overseeing the movement of goods from suppliers or manufacturers to the point of sale.
- **Electronic Data Interchange (EDI)** is a computer-to-computer exchange of business documents, such as purchase orders and invoices, in a standardized electronic format between business partners.
- **Horizontal Integration**: Horizontal integration involves a business expanding its holdings by acquiring or merging with another firm operating in the same market.
- **Integration management** serves as the glue that binds the other elements together. It leverages technologies such as Enterprise Resource Planning (ERP) systems to facilitate seamless collaboration and information sharing among the

various components of the supply chain.

- **Internal operations management** focuses on the processes and activities through which a company adds value to its products or services.
- **Inventory management** is a critical activity within the supply chain, ensuring that materials and goods are available in the right quantities, at the right locations, and at the right time.
- **Key Performance Indicators** are measurements used to evaluate supply chain performance.
- **Logistics** refers to the coordination and movement of resources, particularly inputs into the transformation process and finished goods out to customers.
- **Material/goods flow** represents the physical movement of products along the supply chain.
- **QR systems** leverage barcodes and EDI to provide vendors with real-time sales data for prompt replenishment of goods in the correct quantities – a just-in-time (JIT) approach for retail.
- **Radio Frequency Identification (RFID)** utilizes radio waves to communicate data stored on tags attached to objects, such as product details, shipment information, and pricing.
- **Socially responsible supply chain management** encompasses a range of practices promoting ethical, environmentally conscious, and socially responsible operations throughout the supply chain.
- **Supply chain design** is a strategic decision that determines various entities' roles, responsibilities, and geographical locations within the supply chain network.
- **Supply chain** refers to the interconnected network of organizations involved in fulfilling a customer order, from sourcing raw materials to delivering the final product.
- **Supply management** encompasses the procurement and management of suppliers and the cultivation of strong relationships with them.
- **Vendor Managed Inventory (VMI)** is an advanced supply chain relationship where a vendor manages and maintains agreed inventory levels at the customer's location, leveraging access to real-time inventory data.
- **Vertical Integration:** Vertical integration occurs when a firm owns more than

one portion of its supply chain.

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CHAPTER 8: CAPACITY PLANNING & MANAGEMENT

Chapter Overview

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[8.7 The Capacity Planning Process: A Systematic Approach](#)

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[8.9 The Bottleneck Phenomenon and Its Impact on Process Capacity](#)

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8.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Explain the importance of strategic capacity planning and its role in aligning production capabilities with market demand.
- Analyze the broader organizational effects of capacity decisions and evaluate their strategic implications.
- Apply key capacity measures and performance indicators to assess and optimize operational performance.
- Select and justify appropriate capacity measures for different contexts to ensure accurate capacity assessment.
- Identify and analyze the determinants that influence effective capacity in an organization.
- Outline the steps in the capacity planning process and apply them to develop effective capacity strategies.
- Identify bottlenecks in sequential processes and propose strategies to mitigate their impact on overall process capacity.
- Analyze the bottleneck phenomenon and its implications for process capacity and throughput.
- Perform break-even analysis to evaluate capacity alternatives and make informed capacity decisions.
- Explain the relationship between capacity planning and economies of scale and evaluate their impact on long-term capacity decisions.

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8.1 INTRODUCTION

Businesses develop strategies to increase their market share based on their competitive advantage, recognition of the forces in the business environment, how these forces have shaped the demand in the past, and how it can change in the future. In other words, they are trying to find what products and services they should produce to win more customers. Knowing what needs to be produced is the first step. The more critical question for them is whether they have what it takes to do so. Do they have the resources (capacity) they need to meet the demand in the market, and if not, what should change in their operations to make that happen?

This chapter delves into the critical role of strategic capacity planning for products and services. **Strategic capacity planning** aims to achieve an optimal balance where production capabilities align seamlessly with demand. Capacity requirements encompass diverse elements, including equipment, physical space, and skilled workforce. Failure to match production capabilities with demand can have severe repercussions, leading to escalating costs, resource constraints, and potential customer attrition. Given the enduring commitment of resources required, it is imperative to recognize that capacity planning necessitates a long-term perspective.

Strategic capacity planning is a multifaceted endeavour that demands a holistic approach, considering the intricate interplay of various factors. Effective capacity planning ensures operational efficiency and contributes to organizational competitiveness, customer satisfaction, and long-term sustainability. By proactively aligning capacity with demand, organizations can mitigate risks, optimize resource utilization, and position themselves for growth and success in dynamic market environments. Consequently, strategic capacity planning emerges as a critical function that transcends operational considerations and holds profound implications for an organization's overall strategic direction.

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8.2 ORGANIZATIONAL IMPACT OF CAPACITY DECISIONS

Capacity decisions have far-reaching implications that extend beyond operational boundaries. Managers must be cognizant of the broader organizational effects of such decisions and their potential to influence various aspects of the business. Capacity strategies are not merely operational choices but strategic levers that can shape an organization's competitive position and long-term trajectory.

Among the commonly employed capacity strategies are:

1. **Leading Capacity Strategy:** This proactive approach involves increasing capacity and anticipating expected demand. By augmenting production capabilities ahead of time, organizations aim to position themselves favourably to meet future demand effectively and efficiently.
2. **Following Capacity Strategy:** In contrast, this reactive strategy only expands capacity after increased demand. Organizations adopting this approach prioritize minimizing excess capacity and associated costs, opting to scale up operations once demand patterns justify capacity expansions.
3. **Tracking Capacity Strategy:** This incremental approach involves gradually adding capacity over time to align with evolving demand patterns. Organizations employing this strategy seek to maintain a dynamic equilibrium between capacity and demand, adjusting capacity in measured increments as market conditions evolve.

Each strategy carries distinct advantages and trade-offs, influencing factors such as responsiveness to market dynamics, resource utilization, risk exposure, and competitive positioning. Consequently, capacity decisions should be carefully evaluated within the broader organizational context, considering their potential impact on financial performance, operational agility, customer satisfaction, and long-term strategic objectives.

Video: “[The 3 Strategies for Capacity Planning](#)” by [ClickTime](#) [5:14] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

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8.3 KEY CAPACITY MEASURES AND PERFORMANCE INDICATORS

In capacity planning, two critical measures are invaluable tools for assessing and optimizing operational performance: design capacity and effective capacity.

Design Capacity represents the maximum theoretical output rate or capacity as envisioned by the system's design specifications. It is a benchmark for the absolute upper limit of production capabilities under ideal conditions.

Effective Capacity, on the other hand, is a more pragmatic measure that accounts for real-world constraints and allowances. It is derived by subtracting factors such as planned downtime, maintenance, and other operational inefficiencies from the design capacity. Effective capacity provides a more realistic estimate of the achievable output rate, given the practical limitations of the production environment.

These two capacity measures are the foundation for calculating two essential performance indicators: efficiency and utilization.

Efficiency is a measure of how effectively the available effective capacity is being utilized. It is calculated as:

$$\text{Efficiency} = (\text{Actual Output} \div \text{Effective Capacity}) \times 100\%$$

Utilization, conversely, quantifies the extent to which the maximum design capacity is being leveraged. It is calculated as:

$$\text{Utilization} = (\text{Actual Output} \div \text{Design Capacity}) \times 100\%$$

By monitoring and analyzing these performance indicators, organizations can gain valuable insights into their operational performance, identify areas for improvement, and make informed decisions regarding capacity optimization strategies. High efficiency and utilization rates may indicate the need for capacity expansions,

while low rates could signal the presence of bottlenecks, inefficiencies, or excess capacity that requires adjustment.



Example

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 = $(7 \times 3 \times 8) \times (230) = 38,640$ units per week
2. Utilization = $25,000 \div 38,640 = 64.7\%$
Efficiency = $25,000 \div 28,000 = 89.3\%$

The following video summarizes the above concepts in capacity planning.

Video: “[Capacity Planning – Overview and Key Concepts](#)” by [LeanVlog](#) [2:55] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

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8.4 CAPACITY PLANNING: A HOLISTIC APPROACH FOR PRODUCTS AND SERVICES

Capacity refers to a system's inherent potential to produce goods or deliver services within a specified time frame. Capacity planning is a multifaceted endeavour that encompasses both long-term and short-term considerations. Long-term considerations revolve around determining the overall level of capacity required. In contrast, short-term considerations address variations in capacity needs due to seasonal, random, and irregular fluctuations in demand patterns.

Excess capacity arises when actual production falls short of an organization's achievable or optimal level. This often indicates that market demand for the product or service is lower than the firm's potential supply capabilities. Excess capacity is inefficient, leading to increased costs for manufacturers.

Capacity can be categorized into two distinct domains:

Design Capacity and Effective Capacity.

Design Capacity represents the maximum theoretical output rate or capacity as envisioned by the system's design specifications, assuming ideal conditions.

Effective Capacity, on the other hand, is a more pragmatic measure that accounts for real-world constraints and allowances, such as planned downtime, maintenance, and operational inefficiencies.

In the capacity planning process, three key inputs must be addressed:

1. *Capacity Type*: Determining the specific type of capacity required, whether it pertains to production facilities, equipment, human resources, or a combination thereof.
2. *Capacity Quantity*: Quantifying the precise amount of capacity needed to meet anticipated demand effectively and efficiently.
3. *Capacity Timing*: Establishing the optimal timing for capacity expansions or adjustments to align with evolving market conditions and demand patterns.

By carefully considering these inputs and adopting a holistic approach to capacity planning, organizations can

optimize their resource allocation, enhance operational efficiency, and position themselves for long-term success in dynamic market environments.

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8.5 DEFINING AND MEASURING CAPACITY

When selecting a measure of capacity, choosing a metric that does not require frequent updating is advisable. For instance, using dollar amounts as a capacity measure can be problematic, as in the case of a restaurant with a capacity of “\$1 million in annual sales.” Such a measure becomes less reliable over time due to price fluctuations, necessitating constant updates.

In scenarios involving multiple products, measuring capacity in terms of each product is preferable. For example, stating that a firm’s capacity is to produce either 100 microwaves or 75 refrigerators provides greater clarity than simply stating a capacity of 100 or 75 units. This approach avoids ambiguity and ensures accurate capacity assessments for each product line.

An alternative method of measuring capacity is referring to the availability of inputs. This approach can be particularly useful when dealing with diverse output types, as it allows for a more holistic assessment of the resources required for production.

It is crucial to recognize that no single measure of capacity can be universally applied across all situations. The appropriate capacity measure must be tailored to the specific context and requirements at hand. Factors such as the nature of the products or services, the production processes involved, and the organization’s operational complexities should guide the selection of the most suitable capacity metric.

Organizations can gain a more accurate and actionable understanding of their production capabilities by adopting a context-specific approach to capacity measurement, enabling informed decision-making and effective capacity planning strategies. The following table shows examples of output and input for capacity measures.

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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8.6 DETERMINANTS OF EFFECTIVE CAPACITY

Effective capacity is influenced by many factors that span various aspects of an organization's operations and external environment. These determinants play a crucial role in shaping the actual output rate and must be carefully considered in capacity planning efforts.

- *Facilities:* The size and provision for expansion are critical factors in facility design. Other facility-related considerations include locational factors, such as transportation costs, proximity to markets, labour availability, and access to energy sources. Additionally, the layout of the work area can significantly impact the efficiency and smoothness of work processes.
- *Product and Service Factors:* The more uniform the output, the greater the opportunities for standardization of methods and materials, leading to increased capacity. Conversely, product or service diversity can introduce complexities that may constrain capacity.
- *Process Factors:* While quantity capability is an essential determinant of capacity, output quality is equally important. If the quality does not meet standards, the output rate decreases due to the need for inspection and rework activities. Process improvements that enhance quality and productivity can result in increased effective capacity. Another process factor to consider is the time required for changeovers between different products or services.
- *Human Factors:* The tasks involved in certain jobs, the array of activities, and the required training, skills, and experience all affect the potential and actual output. Employee motivation, absenteeism, and labour turnover also impact the output rate.
- *Policy Factors:* Management policies can influence capacity by allowing or disallowing capacity options such as overtime, second or third shifts, or alternative work arrangements.
- *Operational Factors:* Scheduling challenges may arise when an organization has differences in equipment capabilities or job requirements. Other areas impacting 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:* Capacity changes can have ripple effects on suppliers, warehousing, transportation, and distributors. If capacity is increased, the supply chain must be able to handle the increase. Conversely, if capacity is decreased, the impact on supply chain partners must be considered.
- *External Factors:* Minimum quality, performance standards, and regulatory requirements can restrict management's options for increasing and utilizing capacity.

By understanding and addressing these determinants, organizations can optimize their effective capacity and align their production capabilities with demand more effectively.



Examples of Capacity Factors

- *Facility Factors*: Expansion potential, strategic location
- *Product & Service Factors*: Uniformity within the product manufactured or service executed
- *Process Factors*: Reducing inspections, efficient equipment adjustments
- *Human Factors*: High employee motivation, low absenteeism, low labour turnover
- *Policy Factors*: Opportunity for overtime and/or additional shifts
- *Operational Factors*: Well-stocked inventory, minimal scheduling delays
- *Supply Chain Factors*: Adaptable distributors
- *External Factors*: 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 low absenteeism and labour turnover. In resolving constraint issues, all possible alternative solutions must be evaluated.

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8.7 THE CAPACITY PLANNING PROCESS: A SYSTEMATIC APPROACH

Effective capacity planning is a systematic process involving several key steps to ensure alignment between an organization's production capabilities and strategic objectives. The capacity planning process can be outlined as follows:



Figure 8.7.1 : The capacity planning process

1. *Estimate Future Capacity Requirements:* The first step involves estimating future capacity needs based on demand forecasts, market trends, and organizational growth plans. This requires a comprehensive

analysis of internal and external factors that may influence capacity requirements over the planning horizon.

2. *Evaluate Existing Capacity and Identify Gaps:* In this step, organizations assess their current capacity levels, including facilities, equipment, and human resources. By comparing existing capacity with forecasted requirements, organizations can identify potential gaps or surpluses that need to be addressed.
3. *Identify Alternatives for Meeting Requirements:* Based on the identified gaps or surpluses, organizations explore various alternatives to align capacity with future needs. These alternatives may include capacity expansions, facility upgrades, process improvements, outsourcing, or capacity reductions.
4. *Conduct Financial Analyses of Alternatives:* Each identified alternative is subjected to rigorous financial analysis to evaluate its economic viability. This includes assessing capital investments, operating costs, potential revenue streams, and financial metrics such as net present value (NPV), internal rate of return (IRR), and payback period.
5. *Assess Qualitative Factors for Alternatives:* In addition to financial considerations, organizations must evaluate qualitative factors for each alternative. These may include strategic alignment, operational flexibility, risk exposure, environmental impact, and organizational culture fit.
6. *Select the Optimal Long-Term Alternative:* Based on the financial analyses and qualitative assessments, organizations select the alternative that best aligns with their long-term strategic objectives, balancing financial viability with operational and strategic considerations.
7. *Implement the Selected Alternative:* Once the optimal alternative has been chosen, organizations develop and execute a comprehensive implementation plan. This may involve acquiring resources, modifying processes, training personnel, and managing change effectively.
8. *Monitor Results and Adjust:* The capacity planning process is iterative and requires continuous monitoring and adjustment. Organizations must track the performance of the implemented solution, monitor changes in demand patterns, and make necessary adjustments to ensure ongoing alignment between capacity and requirements.

By following this systematic approach, organizations can proactively manage their capacity levels, optimize resource utilization, and position themselves for long-term success in dynamic market environments.

8.8 THE SEQUENTIAL PROCESSES AND THE BOTTLENECK

Sequential processes are characterized by a series of steps performed in a specific order, where the output of one step becomes the input for the subsequent step. A classic example of such a process is the manufacturing assembly line, where each workstation receives inputs from the preceding workstation and passes its outputs to the next workstation. In these processes, it is typically assumed that each step is performed by a dedicated staff member, as is the case in assembly line operations.

In sequential processes, achieving a balanced cycle time across all steps is crucial. In other words, there should be minimal variation in the time required for different steps to process one unit of product. For instance, if step 1, step 2, and step 3 take 3, 10, and 5 minutes, respectively, to process one unit of product, two major issues can arise during production:

1. *Inventory Accumulation:* Since step 1 is significantly faster than step 2, products that have already been processed in step 1 will accumulate before step 2, waiting for their turn to be processed. This leads to a buildup of work-in-process inventory, which can be costly due to inventory holding costs and potential quality issues.
2. *Resource Idleness:* Step 3 will consistently need to wait for step 2 for an additional 5 minutes. This is because step 3 completes its work on the current unit in 5 minutes, but step 2 requires 10 minutes to finish its task and feed the output to step 3. As a result, step 3 experiences prolonged periods of idleness, which is costly for the company. Despite paying the staff assigned to step 3 for the entire duration, their productive output is reduced due to the slow input rate from step 2.

The root cause of these issues is the presence of a bottleneck, which is the step with the longest cycle time (in this case, step 2). The bottleneck effectively constrains the overall throughput of the entire process, leading to inefficiencies such as inventory buildup and resource idleness.

It is essential to identify and address the bottleneck step to optimize sequential processes. This may involve capacity expansions, process improvements, or alternative resource allocations to balance the cycle times across all steps. Organizations can improve process flow, reduce waste, and enhance overall operational efficiency by eliminating or mitigating the bottleneck.

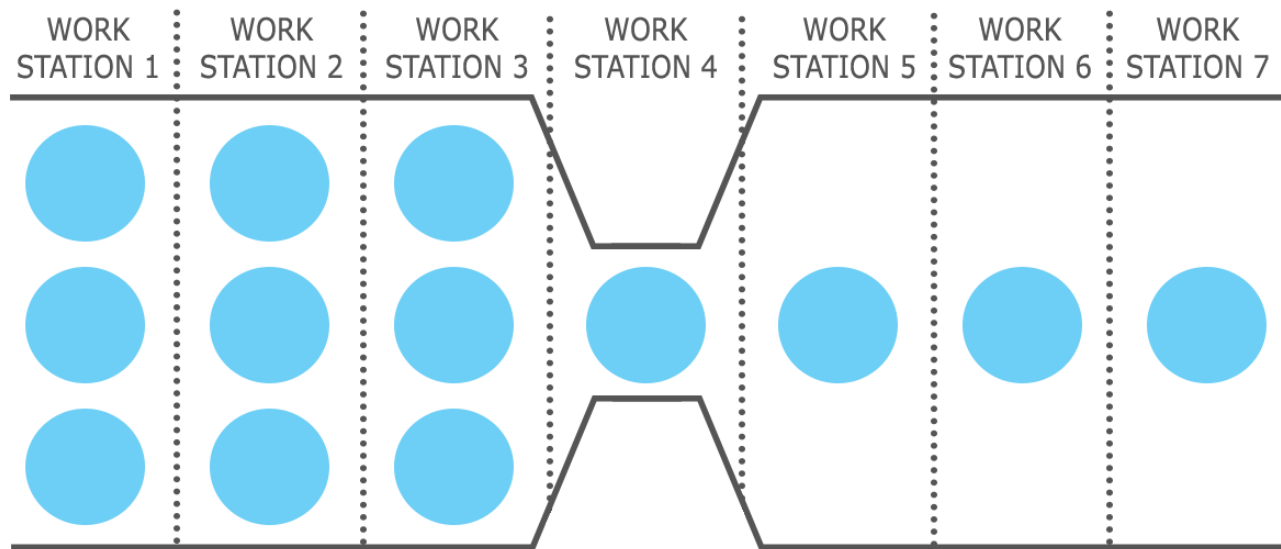


Figure 8.8.1: A diagram displaying the effects of a bottleneck.

Image Description

The image is a diagram of seven workstations arranged horizontally.

- Workstations 1 to 3 are on the left side, each containing three blue circles arranged vertically, indicating multiple tasks or items at each station.
- Workstation 4 is in the center and has a funnel-like shape, narrowing towards the middle, with one blue circle, suggesting a bottleneck or a point of convergence.
- Workstations 5 to 7 are on the right side, each containing one blue circle, indicating fewer tasks or items per station compared to Workstations 1 to 3.

The diagram visually highlights the congestion at Workstation 4, demonstrating that while the initial workstations handle multiple tasks, the central workstation significantly limits throughput before tasks continue to the final stations.

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8.9 THE BOTTLENECK PHENOMENON AND ITS IMPACT ON PROCESS CAPACITY

The **bottleneck** is defined as the slowest step in a process or the slowest process in a system. The capacity of the bottleneck effectively determines the capacity of the entire process. In the previous example, step 2 was identified as the bottleneck due to its longer cycle time of 10 minutes. Consequently, the entire process, comprising steps 1 to 3, cannot achieve an output rate faster than one unit every 10 minutes, regardless of the capabilities of the other steps.



Example

To illustrate this concept, consider an 8-hour shift per day, which equals 480 minutes. Assuming that step 1 has sufficient input to process during the day, its total output capacity would be $480 \div 3 = 160$ units per day. Similarly, the capacity for step 2 is $480 \div 10 = 48$ units, and the capacity for step 3 is $480 \div 5 = 96$ units.

While step 1 can produce 160 units as input for step 2, the bottleneck step (step 2) can only process a maximum of 48 units per day. Consequently, only 48 units will be available as input for step 3. Despite step 3 having a capacity of 96 units per day, it will only process the 48 units received from step 2. Since step 3 is the final step in the process, its output of 48 units becomes the total output of the entire process per day.

The key observation is that the capacity of the bottleneck step (step 2) ultimately determines the capacity of the entire process. This concept holds significant practical implications. Organizations that fail to recognize and address the bottleneck may invest resources in non-bottleneck areas, resulting in no improvement in the overall process capacity.

Identifying and managing the bottleneck is crucial for optimizing process performance. Strategies such as bottleneck elimination, capacity expansion, or alternative resource allocation can be employed to alleviate the constraints imposed by the bottleneck. By addressing the bottleneck, organizations can unlock the full potential of their processes, enhance throughput, and improve overall operational efficiency.

Video: “[5 production line Bottlenecks to anticipate](#)” by [Visufact Manufacturing](#) [4:41]
is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*



Example

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)
4. Inspecting, packing, and labelling (5 min)

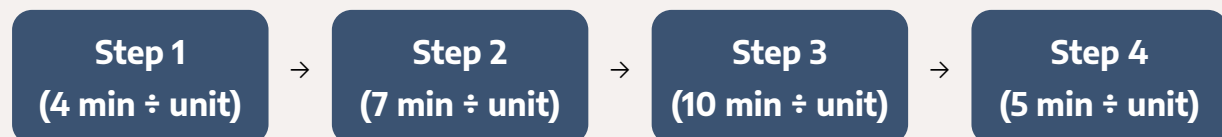


Figure 8.9.1 Flow diagram depicting the time taken for each step of Caroline's manufacturing process.

Employees work 7 hours per day. Help Caroline 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

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

(Based on $7 \times 60 = 420$ 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.

Evaluating Capacity Alternatives

When evaluating capacity alternatives to select the most suitable option, organizations must consider both economic and non-economic factors. This comprehensive approach ensures that the chosen alternative aligns with financial objectives while accounting for broader organizational and societal implications.

Economic Considerations

Economic considerations revolve around assessing the financial viability and potential return on investment for each capacity alternative. The following techniques are commonly employed for economic evaluation:

1. **Break-Even Analysis:** This technique determines the point at which the total revenue from an

alternative equals the total costs associated with implementing and operating that alternative. Break-even analysis provides insights into the minimum level of output or utilization required to recover the investment.

2. **Payback Period:** This method calculates the time required for the cumulative cash inflows from an alternative to equal the initial investment. It helps assess the liquidity and risk associated with each alternative.
3. **Net Present Value (NPV):** The NPV technique discounts the future cash flows of an alternative to their present value, accounting for the time value of money. Alternatives with a positive NPV are considered financially viable, as they generate returns exceeding the required rate of return.

While this chapter focuses primarily on break-even analysis, it is essential to recognize that a comprehensive economic evaluation may involve employing multiple techniques to gain a holistic understanding of the financial implications of each capacity alternative.

Non-economic Considerations

In addition to economic factors, organizations must consider non-economic aspects that can significantly impact the success and acceptance of a capacity alternative. These non-economic considerations include:

1. *Public Opinion:* The perception and sentiment of the general public towards a particular capacity alternative can influence its viability and acceptance.
2. *Employee Reactions:* The attitudes and reactions of employees towards a capacity alternative can affect its implementation and long-term success. Employee buy-in and engagement are crucial factors to consider.
3. *Community Pressure:* Local communities may exert pressure on organizations to adopt or reject certain capacity alternatives based on their potential impact on the environment, local economy, or social fabric.

By carefully evaluating both economic and non-economic factors, organizations can make informed decisions that balance financial objectives with broader organizational and societal considerations, ultimately selecting the capacity alternative that best aligns with their strategic goals and stakeholder expectations.

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8.10 BREAK-EVEN ANALYSIS: A FUNDAMENTAL TOOL FOR CAPACITY EVALUATION

Break-even analysis is a fundamental tool used to evaluate capacity alternatives by determining the point at which total revenue equals total costs. Since capacity utilization typically involves fixed costs, the objective is to identify the output quantity that generates sufficient revenue to cover both fixed and variable costs.

The break-even point (BEP) or break-even quantity (QBEP) represents the volume of output at which total revenue (TR) equals total cost (TC). At this point, the organization neither realizes a profit nor incurs a loss. Mathematically, at QBEP, the following equation holds:

$$TC = FC + VC$$

TC = total cost

FC = total fixed cost

VC = total variable cost

Fixed costs are incurred regardless of the output quantity and remain constant within the relevant range of production. Examples of fixed costs include rental expenses, property taxes, equipment costs, heating and cooling expenses, and certain administrative costs.

To calculate the break-even point, the following notation and relationships are used:

$$TC = FC + VC$$

$$VC = Q \times v \text{ (Variable Cost = Quantity} \times \text{Variable Cost per Unit)}$$

$$TR = Q \times r \text{ (Total Revenue = Quantity} \times \text{Revenue per Unit)}$$

$$P = TR - TC = Q \times r - (FC + Q \times v) \text{ (Profit = Total Revenue - Total Cost)}$$

$$Q_{BEP} = FC \div (r - v) \text{ (Break-Even Quantity = Fixed Cost} \div \text{(Revenue per Unit - Variable Cost per Unit))}$$

By rearranging the equations and substituting the appropriate values, organizations can determine the break-even quantity (QBEP) for a given capacity alternative. This quantity represents the minimum output level required to recover the fixed costs associated with that alternative.

Break-even analysis provides valuable insights into the viability of capacity alternatives by quantifying the relationship between costs, revenue, and output levels. It serves as a crucial decision-making tool, enabling organizations to assess the potential risks and returns associated with each alternative and make informed choices aligned with their financial objectives and operational capabilities.



Example

The management of a pizza place would like to add a new line of small pizza, which will require leasing 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. $Q_{BEP} = FC \div (r-v) = 4000 \div (9-4) = 800$ pizzas month
2. $\text{total revenue} - \text{total cost} = 1200 \times 9 - 1200 \times 4 - 4000 = \$2000$ (i.e. a profit)
3. $P = \$10000 = Q(r-v) - FC$;
Solving for Q will give us: $Q = (10000 + 4000) \div (9-4) = 2800$
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.

Break-Even Analysis for “Make” or “Buy” Decisions

Organizations often face the strategic decision of whether to produce a product or service in-house (“make”) or outsource it to an external supplier (“buy”). Break-even analysis can provide valuable insights to guide this decision by identifying the quantity at which the total cost of making a product in-house equals the total cost of buying it from a supplier.

The key question to be addressed is: “For what quantities would buying the product be preferred to making it in-house, and vice versa?”

Let’s define the following variables:

v_m = per unit variable cost of “make”

v_b = per unit variable cost of “buy”

FC = Fixed cost associated with in-house production

To determine the break-even quantity (Q), we set the total cost of “make” equal to the total cost of “buy”:

Total Cost of “Make” = Total Cost of “Buy”

$$Q \times v_m + FC = Q \times v_b$$

Rearranging the equation, we get:

$$FC = Q \times (v_b - v_m)$$

$$Q = FC \div (v_b - v_m)$$

The break-even quantity (Q) represents the output level at which the total cost of making the product in-house is equal to the total cost of buying it from a supplier.

If the required quantity is greater than the break-even quantity ($Q > FC \div (v_b - v_m)$), it would be more cost-effective to make the product in-house. Conversely, if the required quantity is less than the break-even quantity ($Q < FC \div (v_b - v_m)$), it would be more economical to buy the product from a supplier.

By calculating the break-even quantity and comparing it to the anticipated demand, organizations can make informed decisions regarding the “make” or “buy” strategy that minimizes costs and maximizes profitability. This analysis considers the trade-off between the fixed costs associated with in-house production and the variable costs of outsourcing.

It is important to note that while break-even analysis provides valuable insights, it should be complemented with other factors, such as quality considerations, supply chain risks, strategic alignment, and

long-term implications, to arrive at a comprehensive decision that aligns with the organization's overall objectives.



Example

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:

	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 will it be better to make the product in-house?

Solution

1. $Q_{BEP} = FC \div (v_b - v_m) = 160,000 \div (150 - 100) = 3200$
2. Total cost of "make" = $1000 \times 100 + 160,000 = \$260,000$;
Total cost of "buy" = $1000 \times 150 = \$150,000$

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"

$$160,000 + 100Q < 150Q$$

$$160,000 < 50Q$$

$$3200 < Q$$

Break-Even Analysis for Capacity Choice: Machine A vs. Machine B

When faced with multiple options for producing a product, organizations must evaluate the trade-offs between fixed and variable costs to determine the most cost-effective solution. Break-even analysis can provide valuable insights to guide this decision by identifying the output quantity at which the total cost of using one machine equals the total cost of using another.

The key question to be addressed is: “For what quantities would Machine A be preferred over Machine B, and vice versa?”

Let’s define the following variables:

FC_A = Fixed cost associated with Machine A

v_A = Variable cost per unit of using Machine A

FC_B = Fixed cost associated with Machine B

v_B = Variable cost per unit of using Machine B

Q = Output quantity

To determine the break-even quantity (Q), we set the total cost of using Machine A equal to the total cost of using Machine B:

Total Cost of A = Total Cost of B

$$Q \times V_A + FC_A = Q \times V_B + FC_B$$

Rearranging the equation, we get:

$$FC_A - FC_B = Q \times (v_B - v_A)$$
$$Q = (FC_A - FC_B) \div (v_B - v_A)$$

The break-even quantity (Q) represents the output level at which the total cost of using Machine A is equal to the total cost of using Machine B.

If the required quantity is greater than the break-even quantity ($Q > (FC_A - FC_B) \div (v_B - v_A)$), it would be more cost-effective to use Machine A. Conversely, if the required quantity is less than the break-even quantity ($Q < (FC_A - FC_B) \div (v_B - v_A)$), it would be more economical to use Machine B.

It is recommended that the total cost expressions for each option be written down and simplified to ensure that no additional cost factors are overlooked. The total cost expressions can provide a comprehensive view of all cost components, including fixed costs, variable costs, and other relevant factors specific to the production process or machines under consideration.

By calculating the break-even quantity and comparing it to the anticipated demand, organizations can make informed decisions regarding the most cost-effective machine or production option, minimizing costs and maximizing profitability while aligning with their operational requirements and strategic objectives.



Example

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:

	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. $Q_{BEP} = (FC_B - FC_A) \div (V_A - V_B) = (200,000 - 160,000) \div (150 - 100) = 40,000 \div 50 = 800$
2. **Total cost of Supplier A** = $1000 \times 150 + 160,000 = \$310,000$;
Total cost of Supplier B = $1000 \times 100 + 200,000 = \$300,000$
 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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8.11 CAPACITY PLANNING AND ECONOMIES OF SCALE

The Challenge of Matching Capacity to Demand

Manufacturing firms face a significant challenge in capacity planning: aligning production capacity with fluctuating demand. Unlike perfect scenarios with constant growth, demand often exhibits peaks and troughs. Capacity decisions, however, are long-term. Expanding capacity through machinery and labour acquisition is a relatively inflexible process, especially considering the substantial upfront investments involved.

Economies of Scale: Balancing Fixed and Variable Costs

The concept of economies of scale offers a valuable framework for navigating this challenge. It posits that the average unit cost decreases as the number of units produced increases. This stems from the principle of spreading fixed costs, like machinery depreciation, salaries, and rent, over a larger output volume. Imagine a fixed cost for a single machine. Producing 10 units with that machine will result in a higher average cost per unit compared to producing 100 units.

Leveraging Economies of Scale: Multi-Shift Operations

Manufacturing firms often exploit economies of scale by operating in multiple shifts. By utilizing the same resources (machinery and labour) for extended periods, they can produce more units, driving down the average fixed cost per unit. However, it's crucial to recognize the impact on variable costs, which rise with increased production. These include expenses like electricity, consumables, and temporary labour. Operating multiple shifts necessitates higher utility consumption and additional workforce, leading to an increase in variable costs.

Finding the Optimal Capacity Level

The goal is to identify the optimal capacity level that minimizes total cost (fixed + variable) while maximizing production. This sweet spot represents the point where the decrease in fixed cost per unit due to increased production is offset, but not outweighed, by the increase in variable cost.

Diseconomies of Scale: The Perils of Overexpansion

It's important to note that the cost benefits of economies of scale have limitations. Fixed cost reduction through increased output holds true only until a certain threshold. Beyond this point, additional production necessitates further investments in machinery and labour, leading to a rise in fixed costs. This phenomenon, known as Diseconomies Of Scale, results in an increase in the average unit cost. Diseconomies can arise due to complexities associated with managing a large-scale operation, including potential loss of focus, inefficiencies in resource allocation, and bureaucratic hurdles. These factors can inflate production costs and negate the initial benefits of economies of scale.

Capacity planning in a manufacturing environment requires a nuanced understanding of both economies and diseconomies of scale. By carefully considering the interplay between fixed and variable costs, firms can establish an optimal production capacity that maximizes efficiency and minimizes overall costs while remaining flexible enough to adapt to fluctuating demand.



Example: Economies and Diseconomies of Scale: LED TV Manufacturing

Imagine an LED TV manufacturer, London TV Inc. They are considering expanding their production capacity to meet rising demand. Let's analyze how economies and diseconomies of scale might influence their decision.

Economies of Scale:

- **Scenario 1: Single Shift (Low Production Volume):** London TV Inc. currently operates in a single shift, producing 1,000 LED TVs per day. Fixed costs (factory rent, machinery depreciation) are spread over a smaller output, resulting in a higher average fixed cost per unit (AFCU). Variable costs (raw materials, direct labour) are also lower due to the limited production volume.
- **Scenario 2: Double Shift (Increased Production Volume):** London TV Inc. decides to implement a double shift, effectively doubling their production to 2,000 LED TVs per day. The fixed costs remain relatively constant but are now spread over a larger output. This leads to a significant decrease in AFCU. Variable costs will increase due to additional labour and utility consumption, but likely at a lower rate compared to the fixed cost reduction. The overall average cost per unit (ACU) decreases due to economies of scale.

Diseconomies of Scale:

- **Scenario 3: Triple Shift (Excessive Production Volume):** Enticed by continued demand growth, London TV Inc. pushes for a triple shift, aiming for 3,000 LED TVs daily. While AFCU continues to decrease, additional challenges arise. Managing a larger workforce and complex logistics can lead to inefficiencies. More equipment might necessitate additional factory space, increasing fixed costs. Variable costs for raw materials, labour, and utilities soar. The overall ACU might start to increase due to diseconomies of scale.

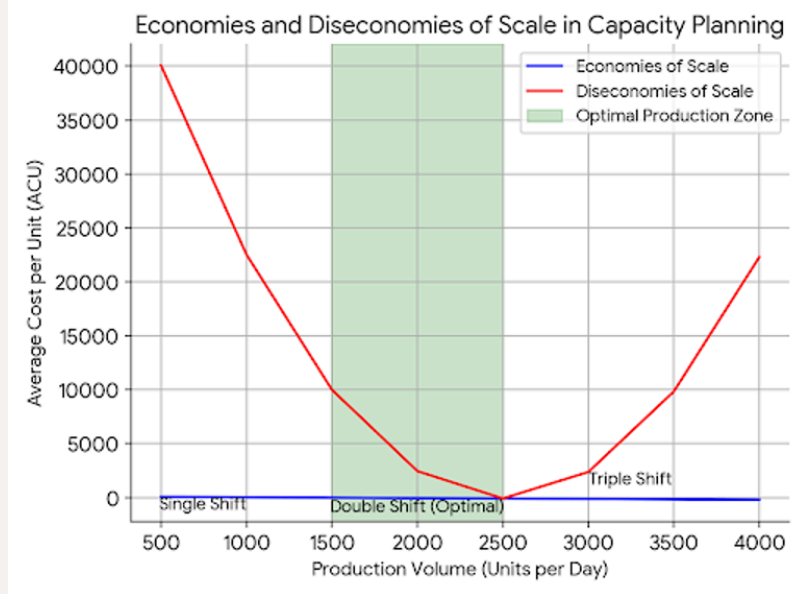


Figure 8.11.1: Economies and Diseconomies of Scale. Microsoft. (2023). *Copilot* [Large language model]. <https://copilot.microsoft.com/> Prompt details provided below.

Prompt Detail

Prompt: Can you share an example with a figure for 'Economies and diseconomies of scale' in capacity planning? I need a figure with an example
import matplotlib.pyplot as plt

import numpy as np

Define production volume

production_volume = np.arange(500, 4001, 500)

Simulate average cost per unit (ACU) with economies and diseconomies of scale

acu_economies = 100 - 0.075 * production_volume # Decreasing cost due to economies of scale

acu_diseconomies = acu_economies + 0.01 * (production_volume - 2500)**2 # Increasing cost due to diseconomies

Plot ACU vs production volume

```

plt.plot(production_volume, acu_economies, label='Economies of Scale', color='blue')
plt.plot(production_volume, acu_diseconomies, label='Diseconomies of Scale',
color='red')
plt.xlabel('Production Volume (Units per Day)')
plt.ylabel('Average Cost per Unit (ACU)')
plt.title('Economies and Diseconomies of Scale in Capacity Planning')
plt.legend()
# Indicate optimal production zone
plt.axvspan(1500, 2500, alpha=0.2, color='green', label='Optimal Production Zone')
plt.legend()
# Add annotations for key points
plt.annotate('Single Shift', xy=(1000, acu_economies[1]), # Point A
arrowprops=dict(facecolor='black', shrink=0.05),
horizontalalignment='right', verticalalignment='top')
plt.annotate('Double Shift (Optimal)', xy=(2000, acu_economies[3]), # Point B
arrowprops=dict(facecolor='black', shrink=0.05),
horizontalalignment='center', verticalalignment='top')
plt.annotate('Triple Shift', xy=(3000, acu_diseconomies[5]), # Point C
arrowprops=dict(facecolor='black', shrink=0.05),
horizontalalignment='left', verticalalignment='top')
plt.grid(True)
plt.show()

```

The optimal production level for London TV Inc. lies in the zone of economies of scale (Scenario 2), where the Average Cost per Unit curve reaches its minimum point. Beyond

this point (Scenario 3), diseconomies of scale set in, causing the Average Cost Per Unit to rise.

Video: “[Economies of Scale in One Minute: Definition/Theory, Explanation and Examples](#)” by [One Minute Economics](#) [1:44] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

“[4.11 Capacity Planning and Economies of Scale](#)” from [Fundamentals of Operations Management](#) by Azim Abbas and Seyed Goosheh is licensed under a [Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License](#), except where otherwise noted.

Microsoft. (2024, June 4). *Copilot* [Large language model]. <https://copilot.microsoft.com/>.

8.12 CHAPTER SUMMARY & REVIEW



Summary

The chapter discusses key capacity strategies (leading, following, and tracking) that organizations can adopt based on anticipated demand, and highlights the significance of choosing the right strategy to ensure responsiveness and efficiency. Additionally, the chapter introduces essential capacity measures such as design capacity (the maximum theoretical output) and effective capacity (accounting for real-world constraints), along with performance indicators like efficiency and utilization that help assess operational performance.

The chapter further explores the capacity planning process, outlining a systematic approach to estimate future capacity requirements, evaluate existing capacity, identify and analyze alternatives, and select and implement the optimal solution. This process ensures that organizations can proactively manage their capacity levels, optimize resource allocation, and enhance operational efficiency. Key steps include estimating future capacity needs, evaluating current capacity, identifying gaps, conducting financial and qualitative analyses of alternatives, and continuously monitoring and adjusting capacity plans to adapt to changing demand patterns.

Moreover, the chapter discusses the bottleneck phenomenon and its impact on process capacity, illustrating how bottlenecks constrain overall throughput and necessitate targeted interventions to balance cycle times and improve efficiency. Strategies for evaluating capacity alternatives, including break-even analysis for economic decision-making, are also covered. The chapter concludes with a discussion on economies and diseconomies of scale based on average long-term total cost, emphasizing the balance between fixed and variable costs to find the optimal capacity.

level while avoiding the pitfalls of overexpansion. Through these insights, organizations can align capacity with strategic objectives, ensuring long-term competitiveness and sustainability.

OpenAI. (2024, June 7). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than three paragraphs. Reviewed by authors.*



Review Questions

1. What are the three common capacity strategies organizations can adopt? Discuss the advantages and disadvantages of each.
 2. How do you calculate efficiency and utilization in capacity planning? Provide examples of how these measures can be used to identify areas for improvement in an organization.
 3. Identify and explain at least three factors that influence effective capacity. How can these factors impact an organization's overall production capacity?
 4. Outline the key steps in the capacity planning process. Why is it important for organizations to continuously monitor and adjust their capacity plans?
 5. Explain the concept of a bottleneck in a sequential process. How does a bottleneck affect overall process capacity, and what strategies can be employed to manage it?
 6. Describe how break-even analysis can be used to evaluate capacity alternatives. What are the key components of the break-even point calculation?
 7. Using break-even analysis, how can an organization determine whether to produce a product in-house or outsource it to a supplier? Provide a detailed example to illustrate your explanation.
 8. What are economies of scale, and how do they affect capacity planning decisions? Discuss the potential pitfalls of diseconomies of scale and provide an example scenario.
 9. Beyond economic factors, what non-economic considerations should organizations consider when evaluating capacity alternatives? How can these considerations impact decision-making?
 10. How can organizations determine the optimal capacity level that balances fixed and variable costs while maximizing production efficiency? Discuss the challenges of matching capacity to fluctuating demand.
-

OpenAI. (2024, June 7). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create ten discussion questions based on the attached chapter document that assess the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

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8.13 KEY TERMS



Key Terms

- **Bottleneck:** The slowest step in each process or the slowest process in a system.
- **Break-Even Analysis:** determines the point at which the total revenue from an alternative equals the total costs associated with implementing and operating that alternative.
- **Capacity** refers to a system's inherent potential to produce goods or deliver services within a specified time frame.
- **Design capacity:** Refers to the maximum designed capacity or output rate.
- **Economic considerations:** Consider the cost, useful life, compatibility, and revenue for each alternative.
- **Effective capacity:** This is the design capacity minus personal and other allowances.
- **Efficiency** is a measure of how effectively the available effective capacity is being utilized.
- **Following capacity:** Where companies wait for demand increases before expanding capabilities.
- **Leading capacity:** Where capacity is increased to meet expected demand.
- **Net Present Value (NPV):** discounts the future cash flows of an alternative to their present value, accounting for the time value of money
- **Non-economic considerations:** Include public opinion, employee reactions, and community pressure.
- **Payback Period:** calculates the time required for the cumulative cash inflows from an alternative to equal the initial investment.

- **Sequential process:** Any process with several steps, one after another.
- **Tracking capacity:** This adds incremental capacity over time to meet demand.
- **Utilization:** quantifies the extent to which the maximum design capacity is being leveraged

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CHAPTER 9: FACILITY LOCATION STRATEGY

Chapter Overview

[9.0 Learning Outcomes](#)

[9.1 Location Strategy: A Critical Decision](#)

[9.2 Key Factors in Facility Location Decision-Making](#)

[9.3 Methods for Finding the Best Facility Location](#)

[9.4 Strategic Significance of Facility Location Decisions](#)

[9.5 Chapter Summary & Review](#)

[9.6 Key Terms](#)

9.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Explain the strategic importance of facility location decisions and their long-term implications on an organization's profitability and competitiveness.
- Analyze the key factors influencing facility location decisions, including proximity to raw materials, labour considerations, transportation infrastructure, utility costs, tax incentives, customer proximity, and community factors.
- Differentiate the location decision factors for manufacturing and service organizations, recognizing each industry's unique priorities and considerations.
- Apply quantitative methods, such as the Location Factor Rating (Weighted Scoring Model) and the Centre of Gravity method, to evaluate and compare potential facility locations based on specific operational requirements and strategic objectives.
- Assess the impact of e-commerce and web-based retail industries on facility location decisions, particularly for service-oriented companies.
- Develop a comprehensive facility location strategy that aligns with the organization's objectives, optimizes operational efficiency, minimizes costs, and enhances responsiveness to customer demands.

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9.1 LOCATION STRATEGY: A CRITICAL DECISION

Although operations managers may not be directly involved in selecting a new site, determining the geographic location of operations is a crucial strategic decision every organization must make systematically across all sectors. This choice has long-term implications for profitability, as it involves substantial capital investment that accounts for a significant portion of operating costs. In the retail industry, for instance, where companies purchase or lease physical spaces, location expenses can constitute over 40% of total operating expenditures.

Factors Influencing Location Decisions

The factors influencing location decisions vary depending on whether the organization is engaged in manufacturing or service provision. Service-oriented businesses like fast-food chains, banks, ATMs, and movie theatres must be near their customer base. In contrast, manufacturers operating at the production end of the supply chain, such as those in agriculture, mining, or soap manufacturing, are less constrained by customer proximity and are instead driven by factors like access to raw materials and the availability of affordable labour.

Consequently, an organization's location decision is shaped by numerous factors, considering:

The nature of the industry (manufacturing or service)

The type of product or service offered

The Rise of E-Commerce and Its Impact

It is essential to consider the establishment of web-based retail industries and their tremendous growth. Services provided by companies like Amazon and numerous other players can be accessed from anywhere, at any time of the day. As a result, these companies' provision of services is much less dependent on location decisions. Numerous service companies are adopting strategies to reduce operating costs by eliminating the need for traditional brick-and-mortar facilities. Banks encourage customers to access various services through their websites; clothing can be purchased online, and other needs can be fulfilled through e-commerce platforms. However, this trend is predominantly applicable to service-oriented companies. Manufacturing organizations still need to produce goods, so making location decisions is a critical strategic consideration.

Prioritizing Location Factors for Optimal Performance

The decision of where to locate an organization's facilities is influenced by numerous factors. However, the relative importance of these factors varies depending on the specific situation and how the facility location impacts the organization's overall performance. When a company needs to establish a new manufacturing facility, for instance, several key factors come into play to determine the optimal location that minimizes operating costs while ensuring a high level of responsiveness to the market.

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9.2 KEY FACTORS IN FACILITY LOCATION DECISION-MAKING

When deciding on the optimal location for a facility, organizations must carefully evaluate several critical factors that can significantly impact their operational efficiency, cost structure, and market responsiveness. The following are some of the key determinants that drive facility location decisions:

1. *Proximity to Raw Materials and Suppliers:* Organizations that process bulk raw materials often prioritize locating their facilities near the sources of supply. This strategic positioning helps minimize transportation costs associated with procuring raw materials. Examples include paper mills near forests, canneries in farming regions, and fish processing plants near harbours where fishing vessels dock.
2. *Labour:* Research indicates that labour factors are among many organizations' most influential determinants in facility location decisions. Key labour considerations include prevailing wage rates for similar jobs in the area, the availability of a qualified workforce, the average education level of the local population, the degree of union activity, and the community's general work ethic and productivity. Other factors, such as absenteeism rates and employee retention, can significantly impact an organization's location strategy.
3. *Transportation Infrastructure:* Efficient transportation networks, including roads, railways, and ports, are essential for the timely and cost-effective distribution of finished goods to the target market.
4. *Utility and Energy Costs:* The cost and reliability of utilities, such as electricity, water, and natural gas, can significantly impact the overall operating expenses of a manufacturing facility.
5. *Tax Incentives and Regulations:* Local and regional tax incentives and regulatory environments can influence a particular location's financial viability and operational feasibility.
6. *Proximity to Customer Market:* For certain industries, being close to end customers is crucial. Service firms like grocery stores, gas stations, fast-food restaurants, and hospitals must be conveniently accessible to their target markets. Additionally, products with high transportation costs or perishable nature may necessitate locating production facilities near the final consumer markets to reduce logistics expenses and maintain product quality. Examples include concrete manufacturing plants and bakeries.
7. *Community Factors:* Local communities can play a significant role in attracting businesses by offering incentives such as tax waivers or reductions, access to

infrastructure (roads, water, sewer, and utilities), and other enticements. Furthermore, community attitudes towards specific industries can influence location decisions. While some communities may discourage firms associated with potential environmental or social impacts, others may actively welcome them for the economic benefits they bring, including job creation, tax revenue, and economic diversification.

By carefully evaluating and prioritizing these factors based on the specific manufacturing requirements and market conditions, organizations can make informed location decisions that balance cost efficiency and market responsiveness, ultimately enhancing their overall performance and competitiveness.

Video: “[Plant location, Factors affecting Plant Location \[Animated video\]](#)” by [Educationleaves](#) [5:33] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

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9.3 METHODS FOR FINDING THE BEST FACILITY LOCATION

Location Factor Rating Method

One effective method for assisting in the selection of the optimal facility location is the Location Factor Rating, also known as the Weighted Scoring Model. This approach involves the following steps:

1. *Identify Key Location Factors:* Determine the various factors that are crucial in the facility location decision, such as proximity to suppliers, business environment, wage rates, community characteristics, proximity to customers, availability of labour pool, and accessibility to transportation hubs.
2. *Assign Weights:* Assign a weight between 0 and 1.0 to each factor, reflecting its relative importance in the decision-making process. The sum of all weights should equal 1.0.
3. *Score Potential Locations:* Evaluate each potential location site against each factor and assign a score, typically on a scale of 0 to 100, with higher scores indicating better performance for that particular factor.
4. *Calculate Weighted Scores:* For each potential location, multiply the score for each factor by its corresponding weight to obtain the weighted score for that factor.
5. *Determine the Optimal Location:* Sum the weighted scores for each potential location. The location with the highest total weighted score is considered the most attractive option based on the collective evaluation of all factors.



Example

Let's consider an example with three potential locations (Site #1, Site #2, and Site #3) and the following location factors and weights:

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

By calculating the weighted scores for each site, we obtain the following results:

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 exhibits the highest total weighted score when evaluated

against Site #1 and Site #3. Therefore, based on the collective assessment of all factors, Site #2 would be considered the most attractive location for the facility.

The **Location Factor Rating Method** provides a structured and quantitative approach to facility location decisions, allowing organizations to objectively evaluate and compare potential sites based on their specific operational requirements and strategic priorities.

Centre of Gravity Method

When the primary objective is to minimize transportation costs, the **Centre of Gravity Method** can be employed to determine the optimal location for a facility that serves multiple areas or other facilities, such as a warehouse or distribution center. This method utilizes an (X-Y) coordinate system to represent the geographical map of the areas under consideration. It 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.

Visual Representation

Imagine a scenario where each blue star in the following figure represents a market area that needs to be served, and the size of the area corresponds to the demand quantity for that market. The goal is to determine the optimal location (i.e., $\bar{x}$ and $\bar{y}$) for our facility to be set up to serve all these markets while minimizing the total transportation costs.

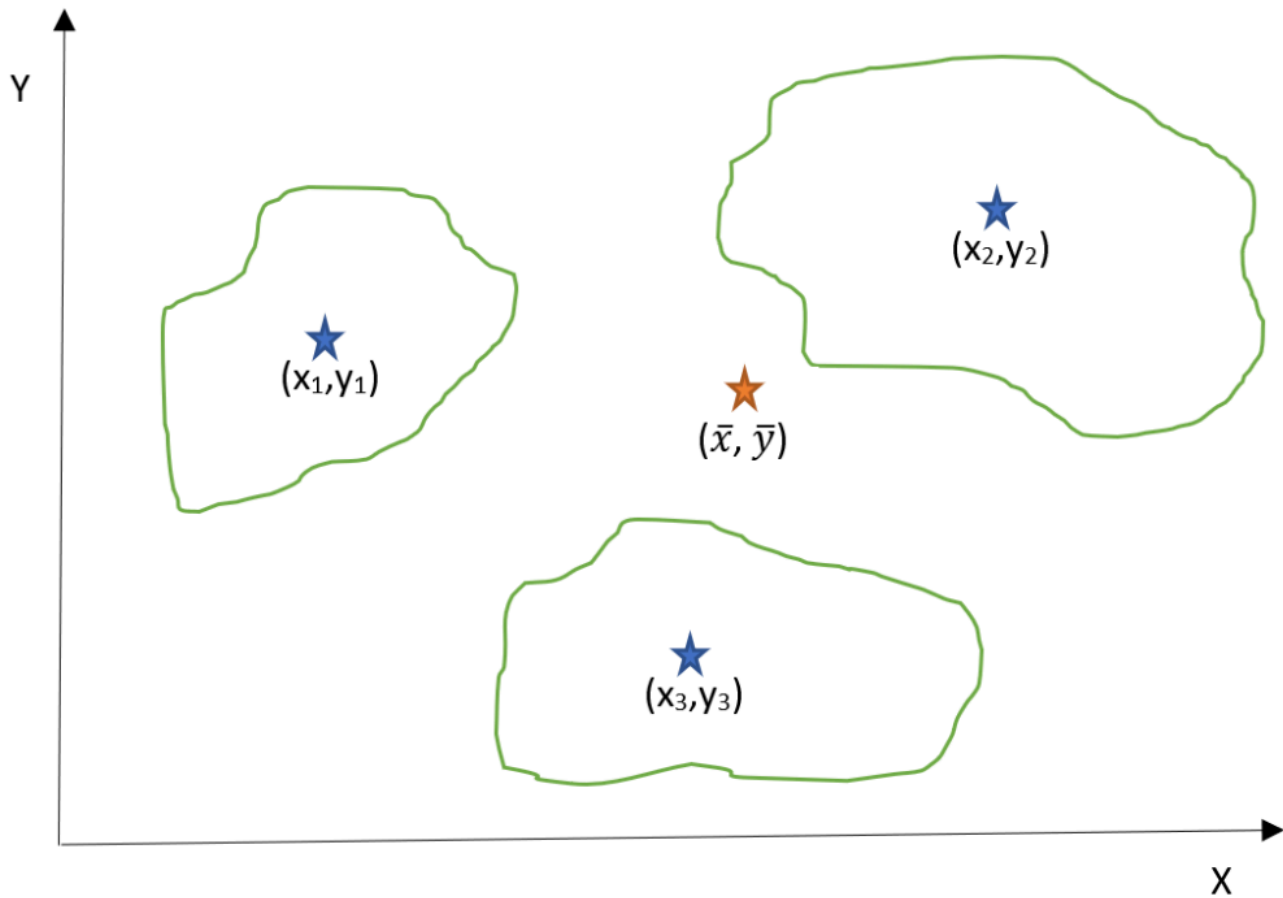


Figure 9.3.1: Three market areas on an X-Y coordinate axis.

Mathematical Formulation

The Centre of Gravity method employs the following formulas to calculate the x and y coordinates for the new facility:

In the following, we show the formulas and use them in an example:

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

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

Where:

$\bar{x}$ = 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

Consider the following information about potential markets and their respective locations:

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

Using the Centre of Gravity method, we can determine the optimal location for the new facility to minimize the total transportation cost:

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

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

By substituting the given values into the formulas, the x and y coordinates for the new facility can be calculated, representing the location that minimizes the total transportation cost while serving all the markets.

The Centre of Gravity method provides a quantitative approach to facility location decisions, specifically when the primary objective is to minimize transportation costs associated with serving multiple areas or facilities. Considering the demand volumes and geographical coordinates, this method helps organizations identify the optimal location that optimizes transportation efficiency and reduces overall logistics costs.

Break-Even Method

A common practice in selecting a business site is to compare the cost of production between multiple locations. The fixed costs (land, building, rent) and variable costs (labour, material, utility, etc.) would be

different in each location. What is common between these sites is that they should produce the forecasted quantity that is demanded in the market. The forecasted demand could be a single quantity (e.g. 10,000 bikes) or fall within a range (e.g. 10,000-20,000 bikes). To determine which location should provide the demanded quantity or quantities, we use a break-even analysis of their production costs or projected profit levels. This can be done by formulating the total cost of each location in a simple linear equation and depicting the total cost graph of all locations, or using Excel to do the same. The following video explains the procedure.

Video: “[Locational Break Even Analysis](#)” by [Stephanie Powers](#) [13:03] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

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9.4 STRATEGIC SIGNIFICANCE OF FACILITY LOCATION DECISIONS

Determining the geographical location of operations is a critical strategic decision for every organization, as it carries far-reaching financial implications. In today's highly competitive business landscape, this decision has gained increasing importance for firms operating in both manufacturing and service sectors. This chapter has provided an in-depth exploration of the factors governing facility location decision-making.

Recognizing that no single factor is the sole determinant in the location decision-making process is important. Identifying the most important factors is directly associated with the organization's objectives. A firm focused on cost minimization would consider different factors for its plant location compared to a firm that prioritizes profit maximization. The relative importance of factors varies depending on the specific industry, operational requirements, and strategic objectives of the organization. Effective facility location decisions require a holistic evaluation of these factors, aligning them with the organization's long-term goals and competitive positioning.

By carefully considering and prioritizing the relevant factors, organizations can make informed decisions regarding the optimal location for their facilities, ultimately enhancing operational efficiency, cost-effectiveness, and responsiveness to customer demands. This chapter has provided a comprehensive framework for understanding and navigating the complexities of facility location decisions, equipping operations managers with the knowledge and tools necessary to make strategic choices that drive organizational success.

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9.5 CHAPTER SUMMARY & REVIEW



Summary

The chapter on Facility Location highlights the strategic significance of choosing the right geographical location for an organization's operations, which has profound implications for profitability and competitiveness. It explores various factors influencing location decisions, such as proximity to raw materials and suppliers, labour availability, transportation infrastructure, utility costs, tax incentives, and proximity to customer markets. The chapter also addresses the impact of e-commerce, noting that while service-oriented companies can often operate with less dependency on physical locations, manufacturing firms still require strategic considerations for their production and distribution facilities.

To aid in making informed location decisions, the chapter presents quantitative methods such as the Location Factor Rating method, which evaluates potential sites based on weighted factors, and the Centre of Gravity method, which aims to minimize transportation costs. It emphasizes that effective facility location decisions require a holistic evaluation of these factors, aligned with the organization's strategic objectives. By systematically assessing and prioritizing these elements, organizations can enhance operational efficiency, cost-effectiveness, and responsiveness to market demands, ultimately achieving a competitive advantage.

OpenAI. (2024, June 11). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Review Questions

1. How do facility location decisions impact an organization's long-term profitability and competitiveness? Provide examples of how different industries might prioritize different factors in their location decisions.
2. Identify and discuss the key factors that influence facility location decisions for both manufacturing and service organizations. How do these factors differ, and why?
3. How has the rise of e-commerce and web-based retail industries affected facility location decisions, particularly for service-oriented companies? What are the implications for traditional brick-and-mortar businesses?
4. Explain the Location Factor Rating method (Weighted Scoring Model) and how it is used to evaluate potential facility locations. What are the advantages and limitations of this method?
5. Describe the Centre of Gravity method and its application in determining the optimal location for a facility. How does this method help in minimizing transportation costs?
6. Discuss how organizations can balance cost efficiency and market responsiveness when making facility location decisions. Provide examples of trade-offs that might need to be considered in this process.

OpenAI. (2024, June 11). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create six discussion questions based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

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9.6 KEY TERMS



Key Terms

- **Centre of Gravity Method** can be employed to determine the optimal location for a facility that serves multiple areas or other facilities, such as a warehouse or distribution center. This method utilizes an (X-Y) coordinate system to represent the geographical map of the areas under consideration.
- **Location Factor Rating Method** provides a structured and quantitative approach to facility location decisions, allowing organizations to objectively evaluate and compare potential sites based on their specific operational requirements and strategic priorities.
- **Key Factors for Location Selection** can be Proximity (to raw material, suppliers, customers market, competition), Cost (labour, production elements, utility and energy, transportation) and regional considerations (government incentives, infrastructure, cultural, societal and legal).

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CHAPTER 10: LAYOUT STRATEGY AND DESIGN

Chapter Overview

[10.0 Learning Outcomes](#)

[10.1 Facility Layout and Market Competition](#)

[10.2 Strategic Benefits of Effective Layout Design](#)

[10.3 Types of Layout](#)

[10.4 Warehouse Layout](#)

[10.5 Manufacturing Layouts](#)

[10.6 Work Cell Layout](#)

[10.7 Material Handling Cost in Process Layout](#)

[10.8 Chapter Summary & Review](#)

[10.9 Key Terms](#)

10.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

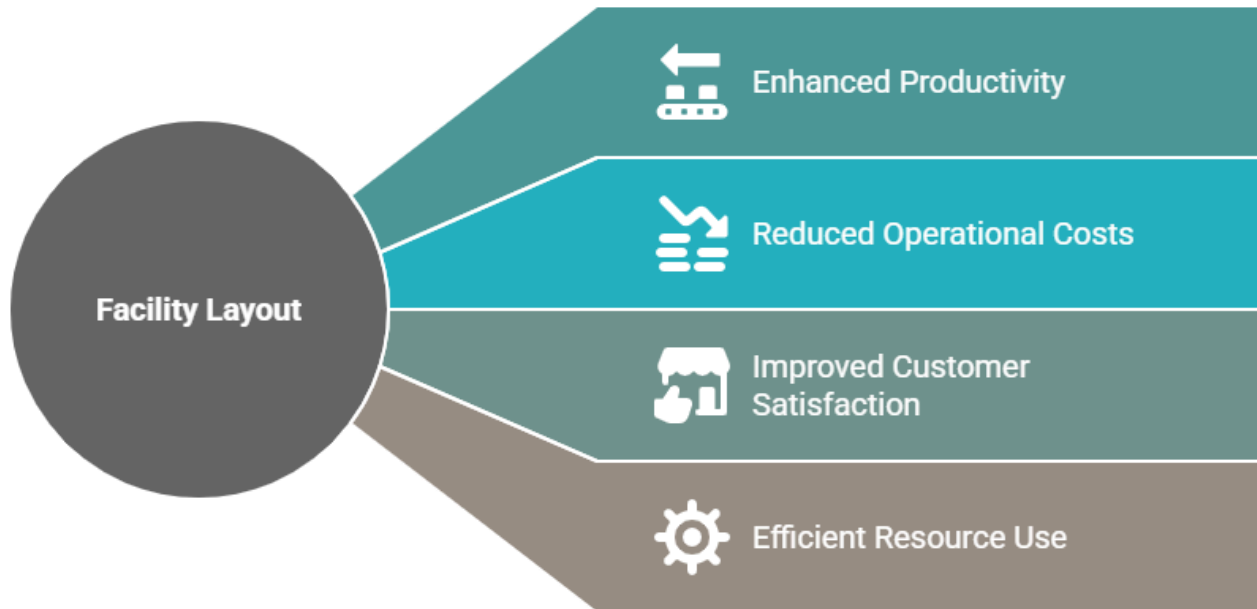
- Discuss the role of facility layout design in achieving competitive advantage and productivity.
- Describe the key considerations in designing the layout.
- Explain the characteristics and properties of non-manufacturing and manufacturing layouts.
- Describe and analyze the advantages and disadvantages of manufacturing layouts.
- Analyze the relationship between material handling cost and layout alterations.
- Explain the properties of the work cell and determine the cell staffing requirements.
- Conduct line balancing analysis and determine the efficiency of allocating workload to workstations.

10.1 FACILITY LAYOUT AND MARKET COMPETITION

Facility Layout is the arrangement of physical spaces, resources, and workflows within an organization to optimize operational efficiency, reduce costs, and improve customer satisfaction.

Facility layout is a strategic, long-term decision that reflects an organization's commitment to operational excellence. It plays a pivotal role in translating business strategy into effective operations by aligning physical space with competitive priorities. A well-designed layout enhances productivity, reduces costs, improves customer satisfaction, and supports the efficient use of resources.

Unveiling the Benefits of Facility Layout



Made with  Napkin

Figure 10.1.1 “Facility Layout Impacts” *generated with [Napkin AI](#), [Napkin Licence](#)*

As discussed in [Chapter 2](#), firms develop strategies to gain a competitive advantage. Facility layout supports these strategies by enabling efficient workflows, facilitating communication, and ensuring adaptability to changing business needs. The layout must align with the firm’s objectives and the nature of its operations, whether manufacturing or service-based.

10.2 STRATEGIC BENEFITS OF EFFECTIVE LAYOUT DESIGN

Effective layout design is fundamental to optimizing operational efficiency, minimizing costs, and fostering a safe and productive work environment. It represents a long-term strategic decision that significantly influences an organization's ability to meet its operational and competitive goals. A well-designed layout supports the seamless flow of materials and information, enhances labour and equipment utilization, ensures safety, and accommodates future changes.

Layout decisions are not merely technical, they are strategic. A thoughtfully designed layout communicates organizational priorities and supports the achievement of competitive advantages. An effective layout contributes to organizational success in several key ways:

Facilitating the Flow of Materials and Information

Efficient layouts minimize unnecessary movement of people and materials.

For example:

- In a *service station*, tools and materials are placed at each workstation to reduce worker movement.
- In a *university setting*, locating the Dean's office near the Vice Chancellor's office facilitates smoother communication and decision-making.

Efficient Utilization of Labour and Equipment

Layouts should ensure that labour and equipment are used to their fullest potential:

For example:

- In *retail*, grocery stores typically attract high foot traffic, justifying larger space allocation. In contrast, an electronics store may experience lower traffic, suggesting the need for space reallocation or repurposing.
- In *car wash operations*, as illustrated in Figure 10.2.1, the process is sequential—washing, rinsing, and drying. If one machine fails, the entire operation halts, highlighting the interdependence of equipment and the critical role of layout in maintaining operational continuity.

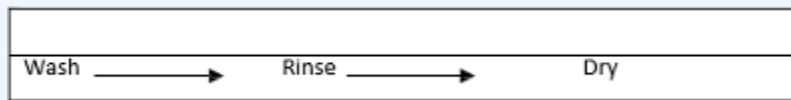


Figure 10.2.1 Car Wash Operation

Enhancing Customer Convenience

Service-oriented layouts must prioritize customer experience:

For example:

- In *bank branches*, high customer volume necessitates layouts that reduce waiting times and streamline service delivery. Proper layout planning can significantly improve customer satisfaction and service efficiency.

Ensuring Worker Safety – Human Factors and Ergonomics

Human-centred design enhances both safety and productivity. **Human Factors** focuses on cognitive aspects of work, while **Ergonomics** address physical capabilities and limitations. Key ergonomic considerations

include workstation design, lighting, noise levels, temperature, airflow, movement flexibility, material handling, and visual/reach zones. Benefits include reduced absenteeism, improved job satisfaction, and enhanced performance in both manufacturing and service settings. Design features such as wide aisles, clear signage, and visual/auditory alerts (e.g., Poka-yoke systems) help prevent errors and injuries

Improving Employee Morale and Communication

Layouts that support collaboration and communication can boost morale and productivity:

- In sectors like *IT, banking, and education*, open and flexible layouts encourage teamwork and knowledge sharing, contributing to a more engaged and effective workforce.

Enhancing Flexibility and Modularity

Modern businesses operate in dynamic environments. Layouts must be adaptable to:

- Accommodate changes in product mix or volume.
- Integrate new technologies.
- Reconfigure workstations and equipment with minimal disruption. Flexible layouts reduce the cost and complexity of future modifications, making them essential for long-term operational resilience.

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10.3 NON-MANUFACTURING LAYOUTS

Layout planning plays a critical role in both manufacturing and service organizations. This section explores key layout types, categorized into *non-manufacturing* and *manufacturing* environments.

Office Layout

Office layouts are designed to optimize the flow of information and work by strategically positioning personnel, equipment, and workspaces. The process typically involves:

- Identifying primary work areas and traffic patterns.
- Analyzing interrelationships among personnel, equipment, and information flow.
- Designing systems that reflect organizational hierarchy and workflow.

A commonly used tool in office layout planning is the **Office Relationship Chart**, which visually represents how the work of one employee affects others. For example, if the Chief Marketing Officer frequently collaborates with the design team, their offices should be located in close proximity.

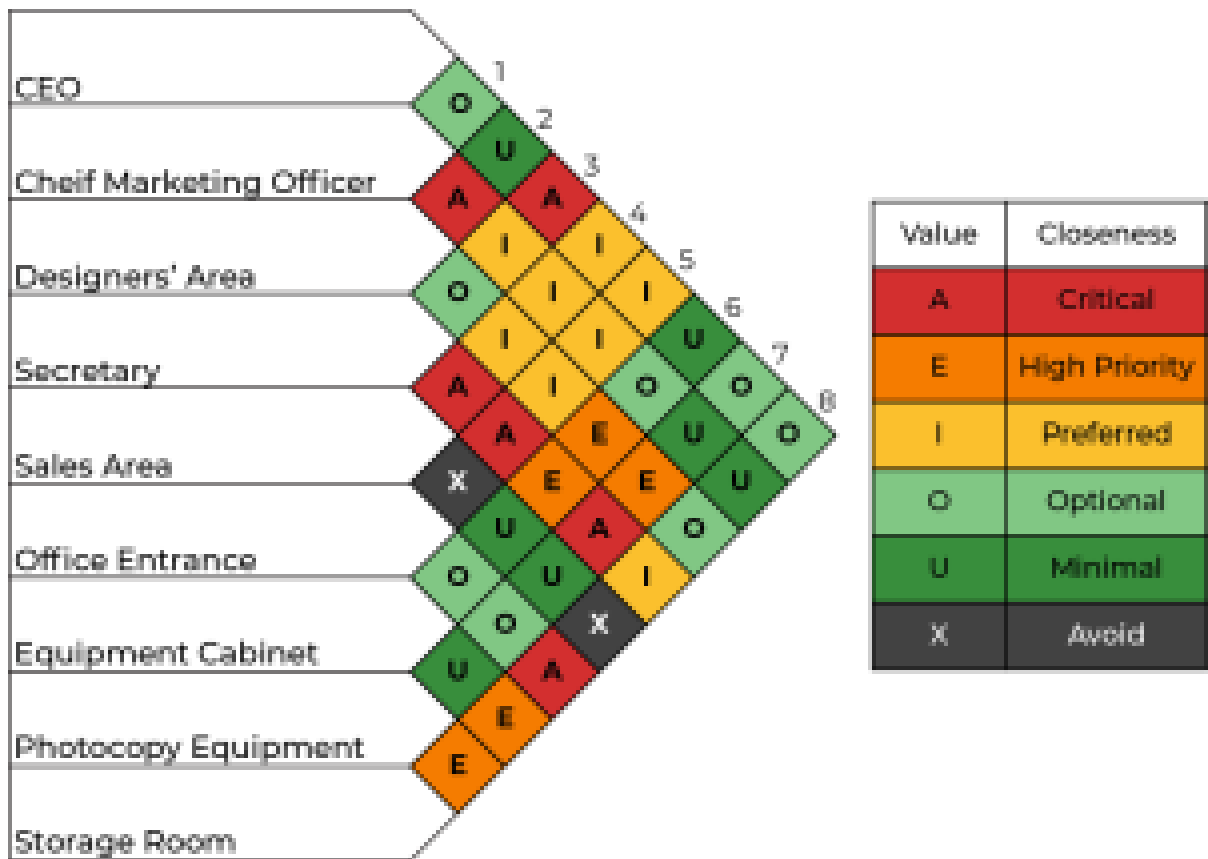


Figure 10.3.1: “Office Relationship Chart” by Koen Liddiard, [CC BY- NC- SA](#)

10.3.1 Image Description

A relationship chart displays workspace proximity preferences among office areas. The left column lists locations: CEO, Chief Marketing Officer, Designers’ Area, Secretary, Sales Area, Office Entrance, Equipment Cabinet, Photocopy Equipment, and Storage Room. A diamond grid shows coded relationships using letters and colours: A (Critical, red), E (High Priority, orange), I (Preferred, yellow), O (Optional, light green), U (Minimal, dark green), and X (Avoid, gray). For example, the CEO has a critical relationship (A) with the Chief Marketing Officer, a preferred relationship (I) with the Designers’ Area, and an optional relationship (O) with the Secretary. The Sales Area should avoid proximity (X) to the CEO and Equipment Cabinet. A legend on the right explains the colour and letter codes representing degrees of closeness and importance.

Retail Layout

Retail layouts are crafted to maximize revenue per square foot by influencing customer behaviour and enhancing the shopping experience. A well-designed layout can attract customers, increase the time they spend in-store, and guide them toward high-margin products. Key objectives of retail layout design include:

- Attracting and retaining customer attention.
- Encouraging exploration and impulse purchases.
- Highlighting best-selling or high-margin merchandise.
- Facilitating smooth traffic flow and reducing congestion.

Several common retail layout types are used depending on the store's goals and space constraints.

Grid Layout

This layout features long, straight aisles that maximize product display and allow customers to browse efficiently. Items are grouped logically (e.g., dishwashing detergents, sponges, and towels) to encourage multi-item purchases.

- *Best suited for:* Grocery stores, pharmacies, and convenience stores.
- *Advantages:* Efficient use of space, easy navigation, and high product visibility.

Figure 10.3.2 "[Grid Store Layout](#)", FDEd (Click to enlarge)

Diagonal Layout

A variation of the grid layout, this design places aisles at an angle to increase product exposure and improve sightlines.

- *Ideal for:* Smaller retail spaces.
- *Benefits:* Enhances visibility and encourages movement through the store.

Figure 10.3.3 "[Diagonal Store Layout](#)", FDEd (Click to enlarge)

Loop Layout (Racetrack Layout)

This layout creates a guided path that leads customers through the entire store, ensuring they pass by all merchandise before reaching the checkout.

- *Used by:* IKEA and similar large-format retailers.
- *Features:* A main corridor with smaller layout variations in central areas.

Figure 10.3.4: "[Loop Store Layout](#)", FDEd(Click to enlarge)

Free-Flow Layout

Unlike structured layouts, this design allows customers to move freely, encouraging browsing and discovery.

- *Best for:* Upscale or experiential retail environments.
- *Design elements:* Power walls, signage, and flexible product displays.

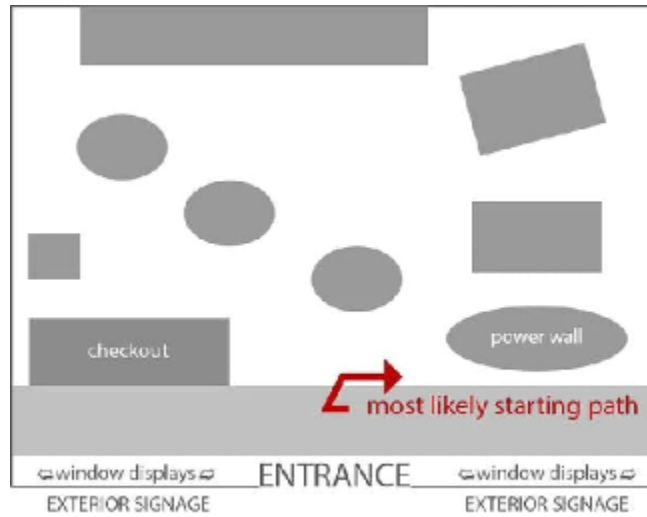


Figure 10.3.5: “Free Flow Layout“, FDEd. (Click to enlarge)

Spine Layout

This layout uses a central aisle (the “spine”) that connects various departments or product zones.

- *Common in:* Department stores and large retail chains.
- *Purpose:* Draws customers deeper into the store while exposing them to featured products.

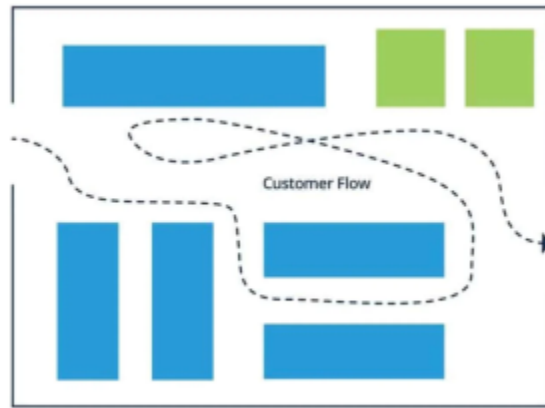


Figure 10.3.6: “[Spine Layout](#)“, FDEd (Click to enlarge)

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10.4 WAREHOUSE LAYOUT

Designing an effective warehouse layout involves striking a balance between two key priorities: maximizing space utilization and minimizing material handling costs. A well-structured layout not only enhances operational efficiency but also facilitates faster order fulfillment, improved inventory control, and safer working conditions.

At its core, warehouse layout planning addresses the following objectives:

- Optimize storage density to make the most of available space.
- Minimize travel distances for picking, put-away, and replenishment.
- Implement appropriate storage systems, such as pallet racks or automated storage and retrieval systems (AS/RS).
- Designate functional zones for receiving, staging, storage, and shipping.

Material Handling Costs and Layout Efficiency

Material handling costs are a major consideration in warehouse design. These costs include not only the physical movement of goods but also the broader operational expenses associated with managing inventory.

Components of material handling cost:

- Receiving and shipping operations
- Internal transportation
- Labour and equipment usage
- Depreciation, insurance, and damage
- Inventory management and supervision

As warehouse size and inventory variety increase, so do the challenges:

- High storage density can make it difficult to locate and retrieve items.
- A large assortment of SKUs increases complexity, which can potentially reduce productivity and lead to delayed deliveries.

Automation in Warehousing: AS/RS Systems

To address these challenges, many warehouses are adopting **Automated Storage and Retrieval Systems (AS/RS)**, which are computer-controlled systems that automatically store and retrieve materials from designated locations, improving speed, accuracy, and efficiency in warehouses or distribution centers. These systems are particularly effective in high-density environments where space and speed are critical.

Benefits of AS/RS:

- Replaces traditional shelving with vertical storage units.
- Saves valuable floor space.
- Enhances safety by reducing manual handling.
- Increases picking speed and accuracy.

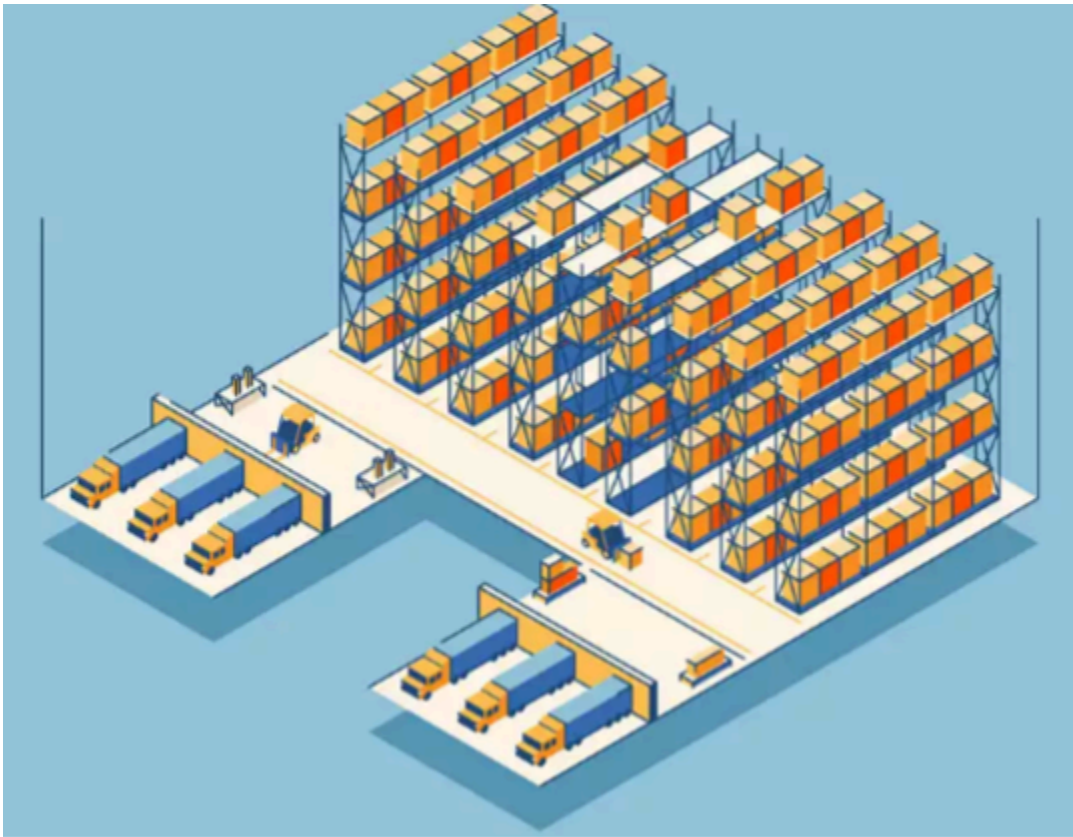


Figure 10.4.1: [Warehouse Layout with Vertical Storage](#) (BigRentz, 2020)

Design Principles for Effective Warehousing

A well-designed warehouse layout should follow four core principles. These are briefly explained in the following video:

Video: “[The 4 Warehouse Design Principles – F.A.C.T.](#)” by [Rob O’Byrne](#) [5:21] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Cross Docking: A Just-in-Time Strategy

In Just-in-Time (JIT) logistics, **cross-docking** is a technique used to minimize storage requirements and expedite delivery. Instead of storing goods, they are transferred directly from inbound to outbound transportation.

Key features of cross-docking:

- Goods are unloaded from inbound trucks and immediately reloaded onto outbound trucks.
- Minimizes storage time and space requirements.
- Reduces warehousing costs and improves delivery speed.

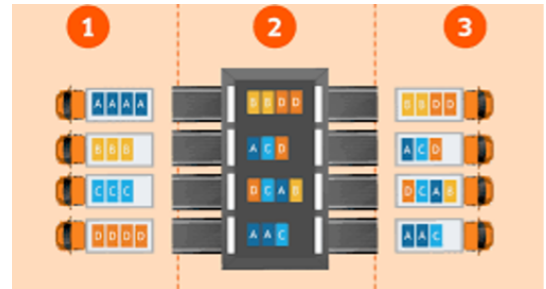


Figure 10.4.2 [Cross Docking](#). (Waredock, n.d.).

10.5 MANUFACTURING LAYOUTS

In manufacturing environments, the layout of facilities plays a pivotal role in determining the efficiency, flexibility, and cost-effectiveness of operations. The layout must be aligned with the *type of production system* adopted by the organization, which in turn is influenced by the company's *strategic objectives*, whether those are cost leadership, product customization, or rapid delivery.



As discussed in [Chapter 5](#), the four primary types of production systems are:

- Job Shop
- Batch Production
- Line Flow
- Continuous Flow

Each system has unique operational characteristics that directly impact layout design. For instance, a company focused on customized, low-volume production may adopt a batch production system, which requires a layout that supports flexibility and varied workflows. Conversely, a company aiming for high-volume, standardized output would benefit from a mass production system, which favours a more rigid and streamlined layout.

It is important to distinguish between layout selection and layout design:

- **Layout selection** is a strategic decision based on business goals.
- **Layout design** is a tactical decision shaped by the nature of the production process.

In reality, many modern manufacturing facilities adopt hybrid layouts to accommodate different stages of production. For example, in an automotive plant, the assembly line may follow a product layout, while the painting process—which involves colour-specific batches—may follow a batch-oriented layout. This hybrid approach enables firms to strike a balance between efficiency and flexibility.

Product Layout

A product layout is most suitable for operations that involve mass production of standardized goods. In this layout, equipment and workstations are arranged in a linear sequence that mirrors the steps of the production process. Each unit follows the same path from start to finish, with minimal variation.

This layout is commonly used in industries such as:

- Automotive manufacturing
- Electronics assembly
- Appliance production
- Service operations with repetitive tasks (e.g., automated car washes)

The defining feature of a product layout is its focus on efficiency through repetition. Because the same product is produced continuously, the layout is optimized for speed, consistency, and minimal handling.

Characteristics of Product Layout

- *High-volume, low-variety production*: The layout is ideal for producing large quantities of identical or similar products.
- *Specialized equipment*: Machines are designed to perform specific tasks at high speed and are arranged in the exact order of operations.
 - Example: In a car wash, Machine 1 performs the washing, Machine 2 handles the rinsing, and Machine 3 completes the drying. Each machine is dedicated to a single function.
- *Streamlined material flow*: The movement of materials is linear and uninterrupted, resulting in reduced confusion and delays.
- *Minimal changeover time*: Since the product remains the same, there is no need to reconfigure machines between production runs.
- *Low work-in-progress (WIP) inventory*: Materials move continuously from one station to the next, minimizing storage needs and reducing material handling costs.

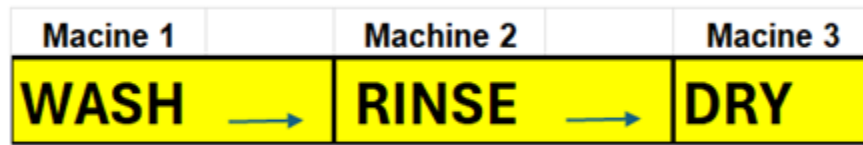


Figure 10.5.1: Business Processes Form a Sequence of Suppliers and Customers

Limitations of Product Layout

Despite its advantages, the product layout also presents several challenges, particularly in environments where flexibility is required:

- *Lack of adaptability:* The layout is rigid and cannot easily accommodate changes in product design or production volume. Any modification may require significant reconfiguration.
- *Low equipment utilization during demand fluctuations:* Specialized machines are efficient only when demand is stable. If demand drops, the equipment may remain idle, leading to inefficiencies.
- *High capital investment:* The machinery used in product layouts is often expensive and designed for specific tasks. To justify the investment, the equipment must operate at high capacity.
- *System vulnerability:* A breakdown in one machine can halt the entire production line.
 - *Example:* If the rinsing machine in a car wash fails, the drying station cannot function, disrupting the entire process.

A product layout is best suited for environments where efficiency, consistency, and high output are the primary goals. However, it requires a stable demand and a standardized product line to be truly effective. Organizations must weigh these benefits and limitations carefully when designing their manufacturing systems.

A process-oriented layout is best suited for environments where a wide variety of products or services are offered in relatively low volumes. Unlike product layouts, which are designed for efficiency and repetition, process layouts prioritize flexibility and customization. This layout groups similar functions or processes together, allowing for a more adaptable workflow that can accommodate diverse customer needs or product specifications.

Organizations typically adopt a process layout when the demand for individual products or services is low, but the range of offerings is broad. This is common in many service industries and custom manufacturing settings. For example, in a retail store, all grocery items are grouped in one section, while apparel, electronics, and books are located in separate areas. Similarly, banks, apparel stores, event venues, and hospitals often utilize process layouts to manage a range of services that require distinct resources and workflows.

Characteristics of Process Layouts

- *Functional grouping:* Workstations or departments are organized by function rather than by product flow. For instance, all billing counters in a bank may be grouped together, separate from customer service or loan processing areas.
- *High flexibility:* The layout can accommodate a wide range of products or services, making it ideal for customized or client-specific operations.
- *Low equipment and labour specialization:* Since demand for each service or product type is relatively low, it is not cost-effective to dedicate specialized equipment or personnel to each task.
- *Variable flow paths:* The movement of materials, people, or information is not linear. Each customer or product may follow a different path through the system.

Example: Retail Store Layout

In a retail environment, the process layout results in a non-linear flow of customer traffic. Each shopper may navigate the store differently, depending on their individual needs. For example:

- Customer A might follow the path: Kids → Grocery → Books → Checkout (as shown by red arrows in Figure 5s.2).
- Customer B might follow a different route: Apparel → Vegetables → Books → Checkout (as shown by blue arrows).

This variability in movement can lead to congestion, inefficient material handling, and difficulty in supervision, especially during peak hours.



Figure 10.5.2 Layout of a Retail Store

Design Considerations for Process Layouts

To address the challenges associated with process layouts—such as jumbled flow and longer travel distances—certain design principles should be followed:

- *Minimize travel distances:* Departments that frequently interact should be located close to each other to reduce material handling time and cost.
- *Sequence departments logically:* Whenever possible, arrange departments in the order of operations to streamline flow.
- *Ensure visibility and accessibility:* Layouts should allow for easy supervision, inspection, and customer navigation.
- *Provide adequate space for movement:* Aisles and pathways should be wide enough to accommodate both customers and material handling equipment without causing obstructions.

A process layout offers the flexibility needed in environments where variety is high and volume is low. While it may not be as efficient as a product layout in terms of speed and throughput, it excels in adaptability, customization, and resource sharing, making it a preferred choice for many service organizations and custom manufacturers.

Fixed-Position Layout

In both process and product layouts, the product typically moves from one machine or workstation to another, while resources such as labour, tools, and machinery remain fixed. However, in the case of large, heavy, or immobile products—such as aircraft, ships, or buildings, the opposite approach is required.

In a fixed-position layout, the product remains stationary, and all necessary resources are brought to the product. This layout is often the only practical option for manufacturing or assembling large-scale items that are difficult or impossible to move during the production process.

Examples of Fixed-Position Layouts

- Shipbuilding
- Aircraft assembly
- Construction sites

The following video reviews some common forms of Fixed-position layouts

Video: “[Industries that use fixed position layout part 2 3](#)” by [Maryanne Ross](#) [1:53] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Hybrid Layout

Some production environments require a combination of both product and process layouts. In such cases, certain activities follow a sequential, standardized flow (as in product layouts), while others require functional flexibility (as in process layouts). This combination is known as a hybrid layout.

A common example is found in automobile manufacturing. During the assembly stage, cars move along a fixed sequence of operations. This reflects a product layout. However, when it comes to painting, cars are grouped by colour and processed in batches, which aligns with a process layout. Thus, the facility utilizes a hybrid layout to efficiently accommodate both types of operations.

Another example can be seen in the food service industry.

- In a dine-in restaurant, customers often order a wide variety of meals in small quantities. This requires flexibility and customization, making a process layout more suitable.
- In contrast, a fast-food restaurant typically serves a limited menu in high volumes, benefiting from a product layout.

With increasing competition, some restaurants now offer both types of services. In such cases, a hybrid layout is adopted:

- High-variety, low-volume items are prepared using a process layout.
- High-volume, low-variety items are produced using a product layout.

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10.6 WORK CELL LAYOUT

A **work cell layout** arranges machinery and equipment to focus on the production of a single product or a group of related products. This layout is designed to improve efficiency by placing all necessary resources within a compact, self-contained area, often in a U-shaped configuration.

Success in work cell environments depends heavily on **cross-functional training**, enabling workers to perform multiple tasks within the cell. This setup enables greater flexibility and autonomy, marking a shift from traditional assembly lines.

Work cells are based on **group technology**, which identifies products with similar characteristics that can be processed together. Cells can be reconfigured to accommodate changes in product types or volumes, offering adaptability in dynamic production environments.

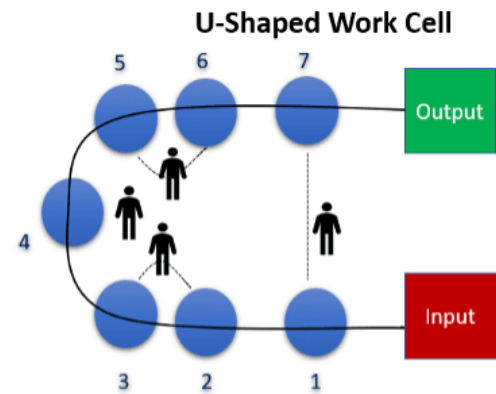


Figure 10.6.1: Work Cell Layout. (Hessing, n.d.).

Benefits of Work Cell Layouts

- Reduced work-in-progress inventory
- Lower material handling and labour costs
- Improved communication and teamwork
- Efficient use of space
- Increased productivity

Video: “[Lean Production Cellular Layout](#)” by [Shrinivas Gondhalekar](#) [8:29] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

10.7 MATERIAL HANDLING COST IN PROCESS LAYOUT

As discussed earlier, cost-effective material handling and layout flexibility are two key considerations in layout design. These are especially important in process layouts, where general-purpose equipment is used to produce a variety of products or services. In process layouts, materials move between departments based on the specific requirements of each order. To minimize material handling cost, departments should be arranged to reduce both the frequency and distance of moves.

Material handling cost depends on:

- F : Frequency of moves between departments
- C : Cost per move (based on distance or time)

The total material handling cost can be calculated using the formula:

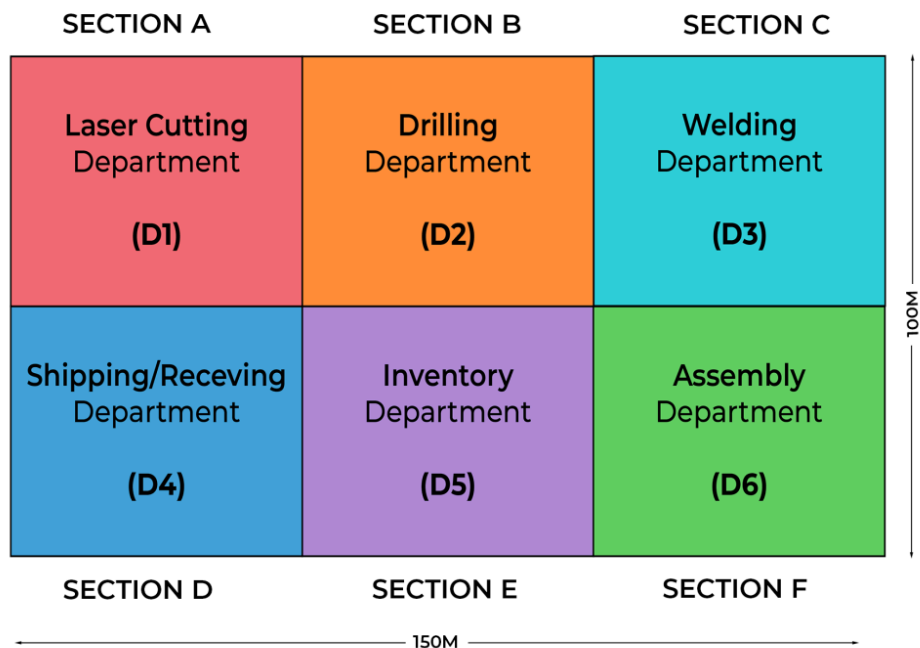
$$\text{MH Cost} = \sum_{i=1}^m \sum_{j=1}^m F_{ij} C_{ij}$$

- m = # of departments
- i, j = individual departments
- F_{ij} = number of loads moved from i to j
- C_{ij} = cost to move a load between i and j



Example Calculation

Consider a factory with six departments producing metal products. The hourly production requires material to move between departments as follows:



- Cost of moving between *adjacent departments*: \$2
- Cost of moving between *non-adjacent departments*: \$4

Production movement between departments

	1	2	3	4	5	6
1		45	90	0	0	25
2			25	45	15	0
3				25	0	90
4					45	0
5						0
6						

a network map showing how product moves between sections (see table above)

Production movement between departments

Using the formula:

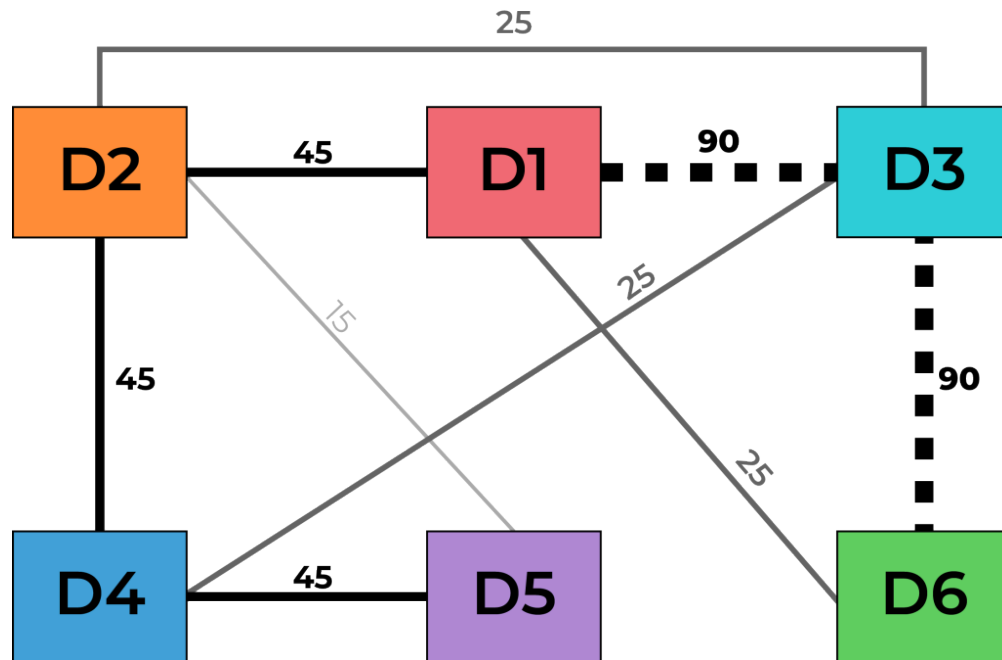
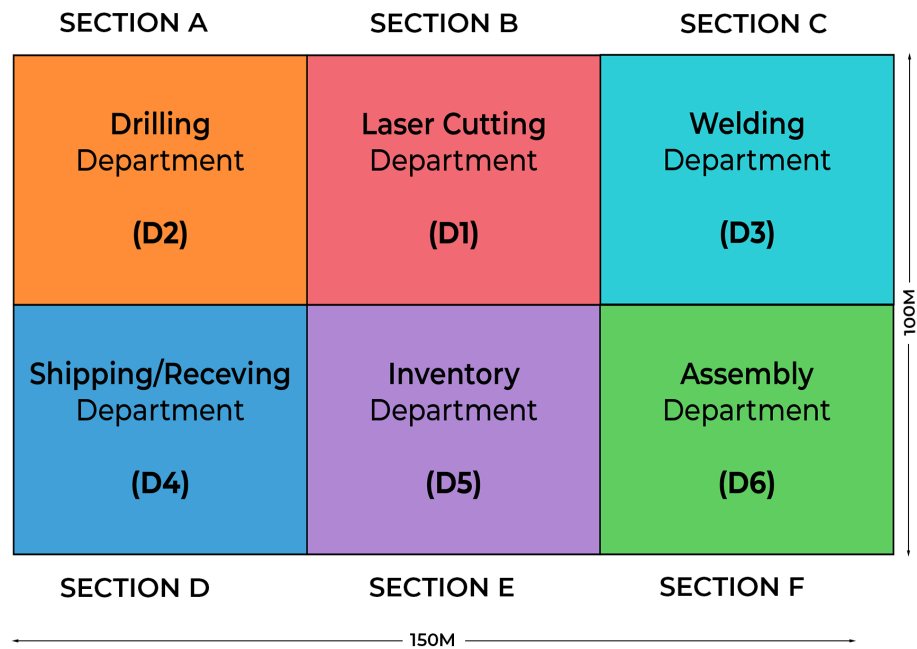
$$\begin{aligned}\text{MH Cost} &= 45(2) + 90(4) + 25(4) + 25(2) + 45(2) + 15(2) + 25(4) + 90(2) + 45(2) \\ &= \$1,090\text{MH}\end{aligned}$$

Reducing Material Handling Cost

To reduce this cost, we can:

- *Decrease the frequency of moves (F)* – though this may not be feasible without altering the production process.
- *Reduce the cost per move (C)* – by rearranging departments to shorten travel distances.

For example, relocating departments so that high-traffic pairs (e.g., Departments 1 & 3 and 3 & 6) are adjacent can reduce costs. After rearrangement:



$$\begin{aligned} \text{New MH Cost} &= 45(2) + 90(2) + 25(2) + 25(4) + 45(2) + 15(2) + 25(4) + 90(2) + 45(2) \\ &= \$910\text{MH} \end{aligned}$$

This simple adjustment results in a cost reduction of \$180 per hour, demonstrating the impact of thoughtful layout design.

Cell Staffing and Balancing Workload

As discussed earlier, work cells operate as self-contained units, where workers collaborate using shared resources and equipment. To ensure the timely delivery of customer orders, it is essential that each work cell is adequately staffed and that the workload is evenly distributed among team members.

To achieve this, two key factors must be considered:

- Order volume
- Available production time

These factors determine the takt time, also known as the desired cycle time (CT_d), which sets the pace of production based on customer demand.

Takt Time Formula

$$\text{Takt Time}(CT_d) = \frac{\text{Available Production Time}}{\text{Required Output (Order Volume)}}$$

Takt time represents the maximum amount of time available to produce one unit in order to meet customer expectations.

$$\# \text{ of workers needed} = \frac{\sum \text{Task times } (CT_a)}{\text{Takt time}}$$



Example

Consider a work cell with seven tasks required to produce a product. The facility operates 8 hours per day, and the customer requires 8 dozen (96 units) of the product daily.

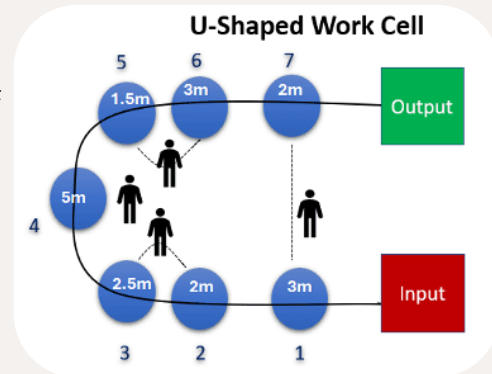
- Available time = 8 hours × 60 minutes = 480 minutes
- Takt time = 480 minutes ÷ 96 units = 5 minutes per unit

This means the cell must produce one unit every 5 minutes to meet demand.

However, the total time required to complete all seven tasks for one unit is 19 minutes. To meet the takt time of 5 minutes, the work must be divided among multiple workers.

$$\begin{aligned}
 \# \text{ of workers needed} &= \frac{\sum \text{Task times } (CT_a)}{\text{Takt time}} \\
 &= \frac{(3 + 2 + 2.5 + 5 + 1.5 + 3 + 2)}{5} \\
 &= 3.8 \text{ or } 4 \text{ workers}
 \end{aligned}$$

Thus, four workers working concurrently in the cell can meet the required output. Each worker would be assigned tasks such that no individual exceeds the 5-minute takt time, ensuring a balanced workload and timely delivery.



“U-Shaped Work Cell” by Six Sigma Study Guide, FDEd. Mods: Added measurements for example.

Assembly Line Balancing

In product-oriented operations, production tasks are divided among several departments or workstations, each responsible for a specific part of the process. A common example is an assembly line, where fabricated parts or modules are assembled step by step across multiple stations.

However, the time required to complete tasks at each station may vary. This can lead to uneven workloads,

where some stations are overburdened while others remain underutilized. Such imbalances can cause delays, bottlenecks, and reduced efficiency.

To address this, the process of line balancing is used. The goal is to distribute tasks across workstations so that each station operates in sync with the desired output rate, also known as the takt time or desired cycle time (CT_d).

Takt Time Formula

$$\text{Takt Time } (CT_d) = \frac{\text{Available Time for Production}}{\text{Required output (order Volume)}}$$

This value sets the pace of production and helps determine how many workstations are needed to meet demand.

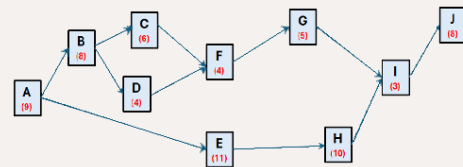


Example

A company is assembling a small suspension system at Meritor Metal. What is the minimum number of stations needed to produce 32 suspension systems in an 8-hour shift?

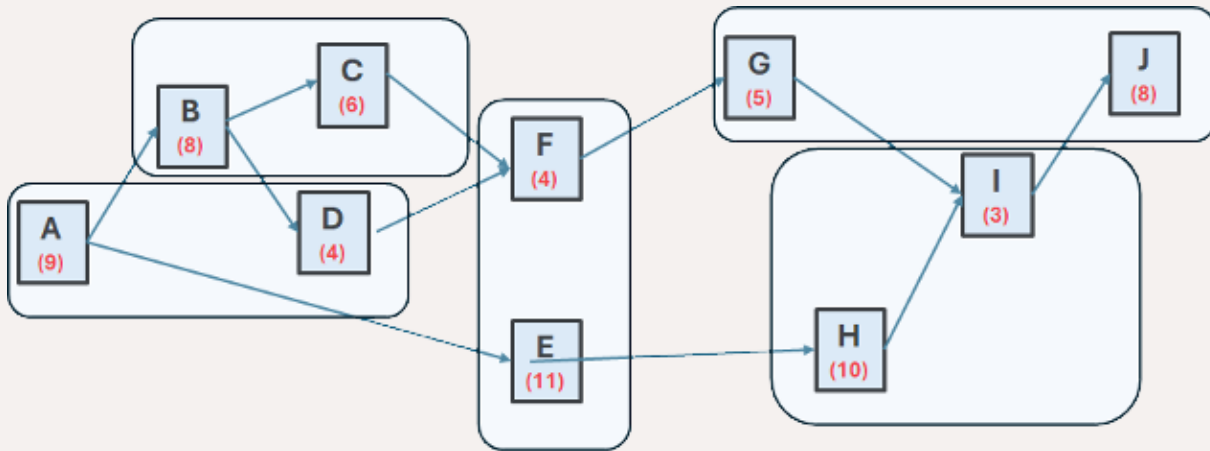
Task	Assembly Time (Minutes)	Preceding Task
A	9	xx
B	8	A
C	6	B
D	4	B
E	11	A
F	4	C,D
G	5	F
H	10	E
I	3	H
J	8	I

The total task time required to produce one unit is 68 minutes. The facility operates for 8 hours per day, and the customer requires 32 units daily.



- Available time = (8hrs)(60) = 480 minutes
- Takt time = 480 minutes ÷ 32 units = 15 minutes per unit
- Minimum number of stations = 68 minutes ÷ 15 minutes = 4.53, rounded up to 5 stations

This means the tasks must be distributed across five stations to meet the required output, as shown below:



Evaluating Line Balancing Efficiency

Once the number of stations is determined, it's important to evaluate how efficiently the tasks are distributed.

Line balancing efficiency is calculated as:

$$\text{Efficiency} = \frac{\text{Total Task Time}}{\text{Number of Stations}} \times \text{Takt Time}$$

Using the example above:

$$\text{Efficiency} = \frac{68}{5} \times 15 = \frac{68}{75} = 0.907 \text{ or } 90.7\%$$

If more stations than necessary are used, efficiency drops. For instance, using 6 stations instead of 5:

$$\text{Efficiency} = \frac{68}{6} \times 15 = \frac{68}{90} = 0.755 \text{ or } 75.5\%$$

This drop in efficiency occurs because some stations would have idle time, leading to the underutilization of resources.

10.8 CHAPTER SUMMARY & REVIEW



Summary

This chapter emphasizes the strategic importance of facility layout design in supporting competitive advantage, productivity, and operational efficiency. A well-designed layout ensures effective material flow, efficient use of labour and equipment, customer convenience, and employee safety and morale. It also highlights the need for layouts to be flexible and modular, allowing them to adapt to changing technologies, product mixes, and business environments. Human factors and ergonomics play a crucial role in reducing absenteeism, enhancing job satisfaction, and improving overall performance. Design features, such as wide aisles, clear signage, and error-prevention systems, also strengthen safety and efficiency.

The chapter explores both non-manufacturing layouts (office, retail, warehouse, fixed-position) and manufacturing layouts (product, process, hybrid, and work cell). Each type is analyzed for its strengths and limitations—for example, product layouts maximize efficiency in high-volume, low-variety production, while process layouts prioritize flexibility and customization. Special attention is given to minimizing material handling costs, optimizing space utilization, and utilizing modern tools such as Automated Storage and Retrieval Systems (AS/RS) and cross-docking to enhance logistics efficiency. Finally, methods such as takt time, work cell staffing, and assembly line balancing are introduced as essential techniques for aligning operations with customer demand while maintaining high efficiency.

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Review Questions

1. What is the strategic importance of facility layout design in achieving a firm's competitive advantage?
 2. List and briefly explain at least four key considerations in effective layout design.
 3. How does efficient material handling contribute to operational cost reduction?
 4. Why is the optimal use of space crucial in layout design, and what are some methods to maximize space utilization?
 5. Describe how information flow can be enhanced through layout design.
 6. Explain the significance of human factors and ergonomics in facility layout planning.
 7. What is meant by flexibility and modularity in layout design, and why are they important in today's business environment?
 8. Discuss the role of energy efficiency in facility layout and provide two methods to achieve it.
 9. Compare and contrast the main characteristics of non-manufacturing and manufacturing layouts.
 10. What are the primary objectives of an office layout, and what tool can be used to optimize it?
 11. Identify key strategies for maximizing profitability in retail layouts.
 12. Explain the concept of cross-docking in warehouse layouts and its impact on warehousing costs.
 13. What are the main differences between product and process layouts in manufacturing?
 14. List two advantages and two disadvantages of a product layout.
 15. In what scenarios would a fixed-position layout be the only feasible option, and why?
-

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create some discussion questions based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

10.9 KEY TERMS



Key Terms

- **Automated Storage and Retrieval Systems (AS/RS)** are computer-controlled systems that automatically store and retrieve materials from designated locations, improving speed, accuracy, and efficiency in warehouses or distribution centers.
- **Cross-docking** is a technique used to minimize storage requirements and expedite the delivery process.
- **Ergonomics** addresses physical capabilities and limitations in the workplace.
- **Facility Layout:** The arrangement of physical spaces, resources, and workflows within an organization to optimize operational efficiency, reduce costs, and improve customer satisfaction.
- **Fixed-Position Layout:** A layout strategy used for large, heavy, or immobile products where the product remains stationary, and workers, materials, and equipment are brought to it.
- **Human Factors** focuses on cognitive aspects of work.
- **Hybrid Layout:** A combination of product and process layouts used when organizations need both efficiency and flexibility.
- **Material Handling Costs:** The total cost associated with the movement, storage, and management of materials within a facility. This includes labour, equipment, transportation, insurance, and damage costs. Efficient layouts aim to minimize these costs to improve profitability.
- **Process Layout:** A layout where similar functions or activities are grouped together, allowing flexibility to handle a wide range of products or services in low-volume, high-variety environments. Common in hospitals, banks, and custom

manufacturing.

- **Product Layout:** A manufacturing layout where equipment and workstations are arranged in a linear sequence based on the production steps. Best suited for high-volume, low-variety products like automobiles or electronics.
- **Office Relationship Chart** is an office layout planning tool that visually represents how the work of one employee affects others.
- **Takt Time:** The maximum amount of time available to produce one unit based on customer demand.
- **Work Cell Layout:** An arrangement of machines, tools, and workers into self-contained units dedicated to producing a single product or group of similar products. Often designed in a U-shape to reduce movement and improve teamwork, communication, and productivity.

CHAPTER 11: TRANSPORTATION MODELS

Chapter Overview

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11.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Explain the importance of transportation models in optimizing the distribution of goods from multiple supply points to multiple demand points.
- Distinguish between balanced and unbalanced transportation problems and describe how to convert unbalanced models into balanced ones.
- Apply and compare initial feasible solution methods: North West Corner, Least Cost, and Vogel's Approximation Method (VAM).
- Test for degeneracy in transportation models and understand its significance for optimization.
- Apply the Stepping Stone and MODI (Modified Distribution) methods to find optimal solutions for transportation problems.
- Analyze and solve practical transportation problems to minimize total transportation cost while meeting supply and demand constraints.

11.1 REACHING MARKET DEMAND

As outlined in [Chapter 2](#), one of the fundamental value propositions that business firms must deliver to their customers is the timely and efficient availability of products in the market. Achieving this objective is closely tied to the geographical positioning of production facilities relative to target markets. Consequently, location strategy becomes a critical component of operational planning.

However, in the dynamic landscape of modern commerce, firms are continually exploring and entering new and geographically dispersed markets. These markets may lie far from existing production sites, thereby introducing logistical challenges and escalating **transportation costs**, factors that can significantly erode profit margins.

To address this, firms often employ strategic tools to optimize their distribution networks. One such method, discussed in [Chapter 2](#), is the **Center of Gravity technique**. This analytical approach enables firms to identify an optimal location for a Distribution Center (DC) that minimizes the total transportation cost to multiple market destinations. By situating the DC at the “center of gravity” of their customer base, firms can streamline logistics: products are shipped in bulk from the production facility to the DC and then distributed to individual markets based on demand.

This hub-and-spoke model not only reduces transportation expenses but also enhances responsiveness to market needs. Figure 11.1.1 illustrates this concept, showing how strategic placement of a DC can serve as a cost-effective intermediary between production and consumption points.

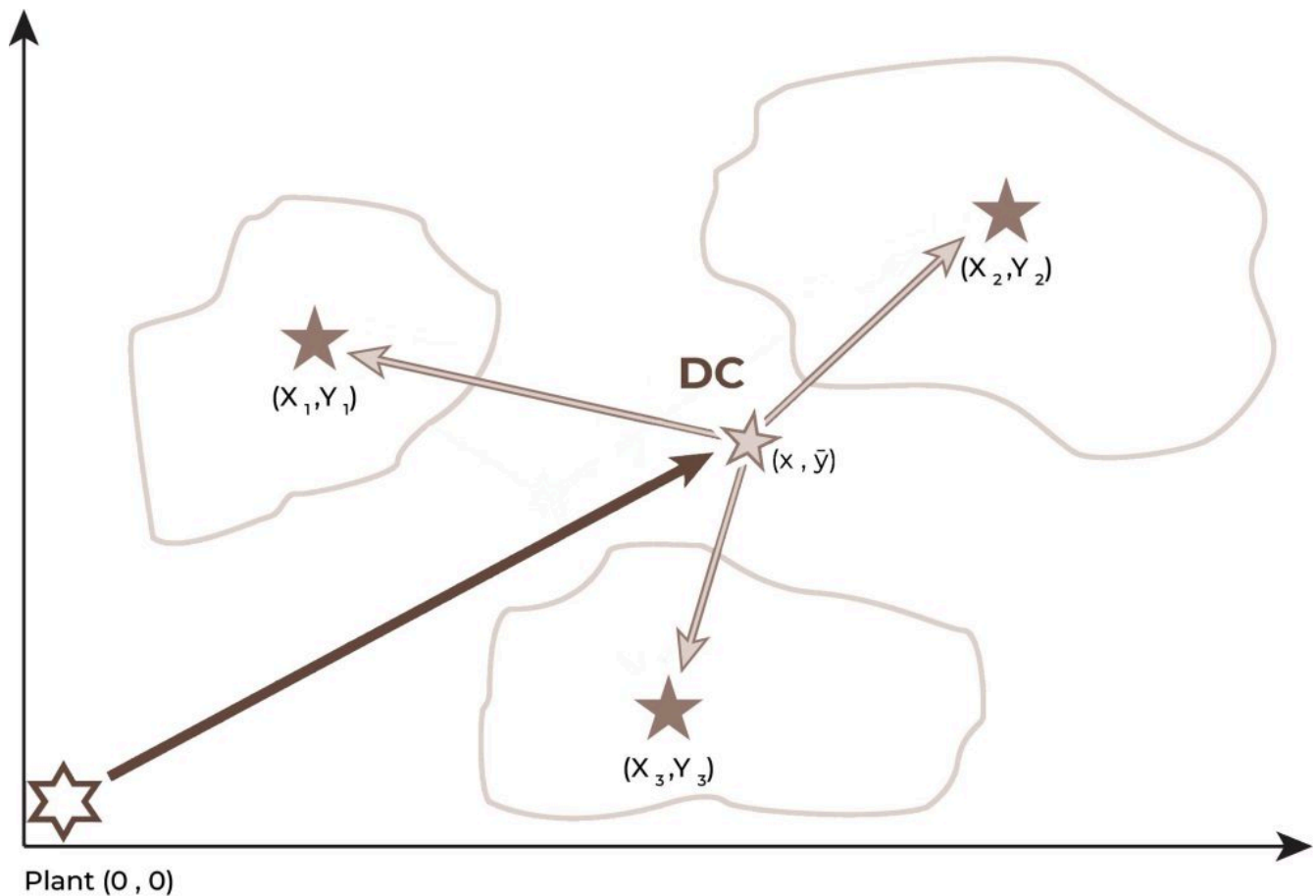


Figure 11.1.1: Three market areas on an X-Y Coordinate axis. [Image](#) by Terri Brown, [CC BY-NC 4.0](#). Mods: Recoloured, added arrows & plant location.

The configuration described above enables flexible and agile delivery of products to the identified markets. However, as market populations grow and demand increases, the capacity of a single Distribution Center (DC)—which is inherently limited by its storage and handling capabilities—may become insufficient. To address these evolving challenges, firms often opt to establish additional DCs.

This expansion leads to a more complex logistics structure in which multiple DCs serve multiple markets. Typically, each DC is strategically positioned to efficiently supply a cluster of markets—often three or more—based on proximity and demand patterns. The resulting configuration forms what is known as a **Transportation Network**, illustrated in Figure 11.1.2.

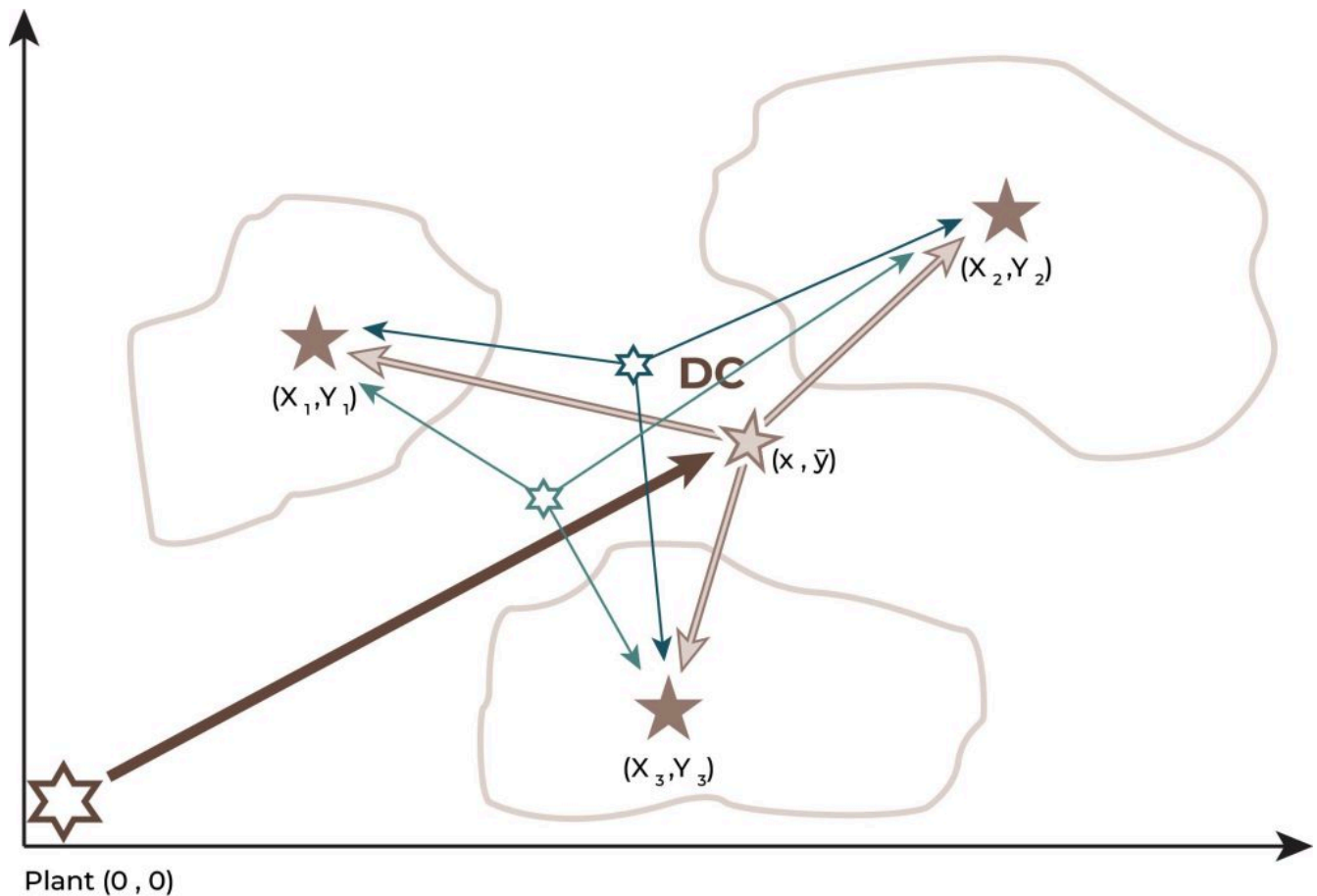


Figure 11.1.2.: Three market areas on an X-Y Coordinate axis. [Image](#) by Terri Brown, [CC BY-NC 4.0](#). Mods: Recoloured, added arrows & plant location.

While the presence of multiple DCs enhances the firm's ability to meet market demand promptly, it also introduces a new layer of complexity: How should goods be allocated from each DC to the various markets to ensure demand fulfillment while minimizing transportation costs?

To answer this question, firms rely on **Transportation Models**, a class of quantitative methods designed to optimize the flow of goods across a distribution network. These models help determine the most cost-effective shipping routes and quantities, ensuring that supply chain operations remain both responsive and economically efficient.

11.2 TRANSPORTATION MODELS

Transportation models represent a specialized class of linear programming problems designed to optimize the allocation and movement of goods or resources from multiple supply locations to multiple demand destinations. In the context of distribution logistics, these models are instrumental in determining the most cost-effective way to transport products from Distribution Centers (DCs) to market locations, while satisfying both supply and demand constraints.

The primary objective of a transportation model is to minimize the total transportation cost across the network, ensuring that:

- The *supply capacity* at each DC is not exceeded,
- The *demand requirements* at each market are fully met, and
- The *cost of shipping* along each route is taken into account.

Key Components of a Transportation Model

- **Supply Points (DCs):** Each DC has a defined capacity, representing the maximum quantity of goods it can supply.
- **Demand Points (Markets):** Each market has a specific demand that must be fulfilled.
- **Transportation Costs:** These are the per-unit costs associated with shipping goods from each DC to each market.
- **Decision Variables:** These represent the quantity of goods to be transported along each route (i.e., from a specific DC to a specific market).

By formulating these elements into a linear programming framework, transportation models enable firms to make data-driven, cost-efficient decisions in complex distribution networks.

The basic structure can be represented in a transportation tableau:

	M1	M2	M3	
DC1	2	4	3	50
DC2	3	1	5	70
DC3	4	2	6	60
	60	80	40	

Transportation Tableau is a matrix used to represent transportation problems, showing supply, demand, and costs.

11.3 BALANCED VS. UNBALANCED TRANSPORTATION MODELS

A transportation model is classified as balanced when the total supply across all sources equals the total demand across all destinations:

$$\sum \text{Supply} = \sum \text{Demand}$$

In such cases, the model can be solved directly using standard transportation algorithms. For example, if both the total supply and total demand equal 180 units, the model is considered **balanced**.

However, when this equality does not hold, the model is termed unbalanced. There are two primary types of **unbalanced models**:

Supply exceeds demand:

$$\sum \text{Supply} > \sum \text{Demand}$$

This indicates surplus capacity at one or more supply points.

Demand exceeds supply:

$$\sum \text{Supply} < \sum \text{Demand}$$

This reflects a shortfall in available supply relative to market needs.



Example

For instance, if the total supply is 180 units and the total demand is only 170 units, the model is unbalanced due to excess supply.

Demand	M1	M2	M3	Supply
DC1	2	4	3	50
DC2	3	1	5	70
DC3	4	2	6	60
Demand	60	80	30	

Converting Unbalanced Models to Balanced Form

To facilitate the use of standard solution methods, unbalanced models are typically converted into balanced models by introducing dummy supply or demand nodes:

- If supply exceeds demand, a **dummy demand point** is added with a demand equal to the surplus. The transportation cost to this dummy point is usually set to zero.
- If demand exceeds supply, a **dummy supply point** is introduced with a supply equal to the shortfall, again with zero transportation cost.

These adjustments ensure that the model becomes mathematically balanced, allowing for the application of classical transportation algorithms.

In the sections that follow, we will first explore the solution of balanced transportation models, followed by techniques for handling and converting unbalanced models.

11.4 SOLVING UNBALANCED MODELS

To solve an unbalanced transportation model, the first step is to convert it into a balanced model by introducing a dummy supply or demand point, depending on the nature of the imbalance.



Example

For example, to balance the unbalanced model on the previous page, where the total supply exceeds the total demand by 10 units, a dummy demand point is added with a demand equal to the surplus, 10 units in this case. This artificial demand point, often labelled as Market 4 (M4), does not represent a real market but serves to absorb the excess supply.

Since M4 is not an actual destination, the transportation cost associated with shipping to this dummy point is set to zero. This ensures that the model remains cost-neutral while satisfying the mathematical requirement of balance.

The resulting transportation tableau below includes this dummy column, allowing the model to be solved using standard optimization techniques. The inclusion of the dummy point ensures that all supply and demand constraints are met without distorting the cost structure of the real distribution network.

Least Cost Method

Step 1: Problem Set Up

	D1	D2	D3	D4	Supply
S1	2	4	3	0	50
S2	3	1	5	0	70
S3	4	2	6	0	60
Demand	60	80	30	10	

There is a 10-unit surplus. To balance the model, a dummy demand point (D4) is created, and the cost of transporting to D4 is set to 0.

Step 2: Find the cell with the lowest cost

- The cell with the lowest cost is S2/D2.
- Allocate 70 units from S2, and adjust the remaining demand in D2 ($80-70=10$) and the remaining supply in S2 ($70-70=0$)

	D1	D2	D3	D4	Supply
S1	2	4	3	0	50
S2	3	(70) 1	5	0	70 0
S3	4	2	6	0	60
Demand	60	80 10	30	10	

Step 3: Find the cell with the next least cost

- The cell with the next least cost is S3/D2.
- Allocate 10 units (the remaining demand from D2) and adjust the supply in S3 and the demand in D2.

	D1	D2	D3	D4	Supply
S1	2	4	3	0	50
S2	3	(70) 1	5	0	0
S3	4	(10) 2	6	0	~~60~~ 50
Demand	60	~~10~~ 0	30	10	

Step 4: Move to the next least cost

- The cell with the next least cost is S1/D1.
- Allocate 50 units from S1 and adjust the demand in D1.

	D1	D2	D3	D4	Supply
S1	(50) 2	4	3	0	~~50~~ 0
S2	3	(70) 1	5	0	0
S3	4	(10) 2	6	0	50
Demand	~~60~~ 10	0	30	10	

- The cell with the next least cost is S3/D1.
- Allocate 10 units from S3 (the remaining demand in D1), and adjust the numbers for supply and demand in S3 and D1.

	D1	D2	D3	D4	Supply
S1	(50) 2	4	3	0	0
S2	3	(70) 1	5	0	0
S3	(10) 4	(10) 2	6	0	~~50~~ 40
Demand	~~10~~ 0	0	30	10	

- The cell with the next least cost is S3/D3.
- Allocate 30 units from S3 (the remaining demand in D3), and adjust the numbers for supply and demand in S3 and D1.

	D1	D2	D3	D4	Supply
S1	(50) 2	4	3	0	0
S2	3	(70) 1	5	0	0
S3	(10) 4	(10) 2	(30) 6	0	40 10
Demand	0	0	30 0	10	

Step 5: Moving to the next least cost

- The last allocation is the remaining units in S3 to the dummy demand (D4).

	D1	D2	D3	D4	Supply
S1	(50) 2	4	3	0	0
S2	3	(70) 1	5	0	0
S3	(10) 4	(10) 2	(30) 6	(10) 0	10 0
Demand	0	0	0	0	

Step 6: Total Transportation Cost Calculation

Use the cost multiplied by the allocation values.

$$\text{Total Cost} = (S1/D1 \times 2) + (S2/D2 \times 1) + (S3/D1 \times 4) + (S3/D2 \times 2) + (S2/D3 \times 6) + (S3/D4 \times 0)$$

$$\text{Total Cost} = (50 \times 2) + (70 \times 1) + (10 \times 4) + (10 \times 2) + (30 \times 6) + (10 \times 0)$$

$$\text{Total Cost} = 100 + 70 + 40 + 20 + 180 + 0$$

$$\text{Total Cost} = 410$$

11.5 SOLVING BALANCED TRANSPORTATION MODELS

Once a transportation model is confirmed to be balanced (the total supply equals the total demand), it can be solved using one of several initial feasible solution methods. These methods differ in their approach and efficiency in minimizing total transportation cost. The goal of each is to generate a starting solution that satisfies all supply and demand constraints.

Common Initial Feasible Solution Methods:

1. **North-West Corner Rule (NWCR):**

This is the most basic method. It begins at the top-left (north-west) cell of the transportation tableau and allocates as much as possible to that cell, then moves either right or down based on remaining supply and demand. While simple, it does not consider transportation costs and often results in suboptimal solutions.

2. **Least Cost Method (LCM):**

This method improves upon NWCR by selecting the cell with the lowest transportation cost for allocation first. It continues to allocate to the next lowest-cost cell, adjusting supply and demand accordingly. This approach generally yields a better starting solution than NWCR.

3. **Vogel's Approximation Method (VAM):**

VAM introduces the concept of opportunity cost by calculating penalties for not using the least-cost routes. It selects allocations based on the highest penalty, thereby balancing cost efficiency with strategic allocation. VAM typically produces the most cost-effective initial solution among the three methods.

These methods will be illustrated using the following example.



Example: Mega Farms Inc.

Mega Farms Inc. operates three strawberry farms—S1, S2, and S3—which supply four regional markets—D1, D2, D3, and D4. The supply capacities and market demands are as follows:

- Supply Capacities:
 - S1: 60 cases
 - S2: 80 cases
 - S3: 100 cases
- Market Demands:
 - D1: 50 cases
 - D2: 70 cases
 - D3: 80 cases
 - D4: 40 cases

The transportation cost per case (in \$) from each farm to each market is provided in the following tableau:

	D1	D2	D3	D4	Supply
S1	\$6	\$2	\$14	\$8	60 Cases
S2	\$4	\$12	\$10	\$18	80 Cases
S3	\$16	\$6	\$6	\$4	100 Cases
Demand	50 Cases	70 Cases	80 Cases	40 Cases	

Mega Farms Inc. wants to determine how many cases should be sent from which farm to which market so that the total cost of transportation is minimized.

11.6 NORTH-WEST CORNER RULE (NWCR)

The North-West Corner Method (NWCN) is a straightforward technique used to generate an initial feasible solution for a balanced transportation model. While it does not consider transportation costs during allocation, it provides a valid starting point for further optimization.

This method is named after the north-west (upper-left) cell of the transportation tableau, where the allocation process begins.

NWCR Steps

1. *Start at the North-West Cell (Top-Left Corner):*
Allocate as much as possible to the cell in the first row and first column (cell (1,1)), subject to the available supply and demand.
2. *Adjust Supply and Demand:*
Subtract the allocated quantity from both the supply of the row and the demand of the column.
3. *Eliminate Satisfied Rows or Columns:*
If the supply for a row or the demand for a column is fully satisfied (i.e., reduced to zero), that row or column is considered complete and is crossed out (highlighted in grey in visual representations).
4. *Move to the Next Available Cell:*
Proceed to the next cell to the right (if a row is still active) or downward (if a column is completed) and repeat the allocation process.
5. *Continue Until Completion:*
Repeat the above steps until all supply and demand values are fully allocated.

Once the initial allocation is complete, the total transportation cost can be calculated by multiplying the quantity allocated to each cell by its corresponding unit transportation cost and summing the results across the tableau.



Example: Mega Farms Inc.

Mega Farms Inc. operates three strawberry farms (S1, S2, and S3) which supplies four regional markets (D1, D2, D3, and D4). The supply capacities and market demands are as follows:

- Supply Capacities:
 - S1: 60 cases
 - S2: 80 cases
 - S3: 100 cases
- Market Demands:
 - D1: 50 cases
 - D2: 70 cases
 - D3: 80 cases
 - D4: 40 cases

The transportation cost per case (in \$) from each farm to each market is provided in the following tableau:

	D1	D2	D3	D4	Supply
S1	\$6	\$2	\$14	\$8	60 Cases
S2	\$4	\$12	\$10	\$18	80 Cases
S3	\$16	\$6	\$6	\$4	100 Cases
Demand	50 Cases	70 Cases	80 Cases	40 Cases	

Mega Farms Inc. wants to determine how many cases should be sent from which farm to which market so that the total cost of transportation is minimized.

Determining the Total Transportation Cost Using the North-West Corner Method

The tableau for this model is shown below:

	D1	D2	D3	D4	Supply
S1	\$6	\$2	\$14	\$8	60
S2	\$4	\$12	\$10	\$18	80
S3	\$16	\$6	\$6	\$4	100
Demand	50	70	80	40	

The steps in solving this problem are:

Step 1: Allocate to (S1, D1)

- Allocate 50 units (the demand of D1).
- Update:
 - S1 remaining supply = $60 - 50 = 10$
 - D1 demand fulfilled = $50 - 50 = 0$

	D1	D2	D3	D4	Supply
S1	(50) \$6	\$2	\$14	\$8	~~60~~ 10
S2	\$4	\$12	\$10	\$18	80
S3	\$16	\$6	\$6	\$4	100
Demand	~~50~~ 0	70	80	40	

Step 2: Allocate to (S1, D2)

- Allocate 10 units (the remaining amount in S1)
- Update:
 - S1 exhausted
 - D2 remaining demand = $70 - 10 = 60$

	D1	D2	D3	D4	Supply
S1	(50) \$6	(10) \$2	\$14	\$8	~~10~~ 0
S2	\$4	\$12	\$10	\$18	80
S3	\$16	\$6	\$6	\$4	100
Demand	0	~~70~~ 60	80	40	

Step 3: Allocate to (S2, D2)

- Allocate 60 units (the remaining demand in D2)
- Update:
 - S2 remaining supply = $80 - 60 = 20$
 - D2 demand fulfilled

	D1	D2	D3	D4	Supply
S1	(50) \$6	(10) \$2	\$14	\$8	0
S2	\$4	(60) \$12	\$10	\$18	~~80~~ 20
S3	\$16	\$6	\$6	\$4	100
Demand	0	~~60~~ 0	80	40	

Step 4: Allocate to (S2, D3)

- Allocate 20 units (the remaining supply from S2)
- Update:
 - S2 exhausted
 - D3 remaining demand = $80 - 20 = 60$

	D1	D2	D3	D4	Supply
S1	(50) \$6	(10) \$2	\$14	\$8	0
S2	\$4	(60) \$12	(20) \$10	\$18	~~20~~ 0
S3	\$16	\$6	\$6	\$4	100
Demand	0	0	~~80~~ 60	40	

Step 5: Allocate to (S3, D3)

- Allocate 60 units (the remaining demand in D3)
- Update:
 - $S3 \text{ remaining supply} = 100 - 60 = 40$
 - D3 demand fulfilled

	D1	D2	D3	D4	Supply
S1	(50) \$6	(10) \$2	\$14	\$8	0
S2	\$4	(60) \$12	(20) \$10	\$18	0
S3	\$16	\$6	(60) \$6	\$4	~~100~~ 40
Demand	0	0	~~60~~ 0	40	

Step 6: Allocate to (S3, D4)

- Allocate the remaining 40 units
- Update:
 - S3 exhausted
 - D4 demand fulfilled

	D1	D2	D3	D4	Supply
S1	(50) \$6	(10) \$2	\$14	\$8	0
S2	\$4	(60) \$12	(20) \$10	\$18	0
S3	\$16	\$6	(60) \$6	(40) \$4	~~40~~ 0
Demand	0	0	0	~~40~~ 0	

After completing the allocation process using the North-West Corner Method, all market demands have been fully satisfied, and the available supply from all farms has been completely utilized. This indicates that a feasible solution has been reached.

To determine the total transportation cost of this initial solution, we multiply the quantity allocated to each cell by its corresponding unit transportation cost and sum the results:

$$\text{Total Cost} = (S1/D1 \times 6) + (S1/D2 \times 2) + (S2/D2 \times 12) + (S2/D3 \times 10) + (S3/D3 \times 6) + (S3/D4 \times 4)$$

$$\text{Total Cost} = (50 \times 6) + (10 \times 2) + (60 \times 12) + (20 \times 10) + (60 \times 6) + (40 \times 4)$$

$$\text{Total Cost} = 300 + 20 + 720 + 200 + 360 + 160$$

$$\text{Total Cost} = 1760$$

Thus, the initial basic feasible solution obtained using the North-West Corner Method results in a total transportation cost of \$1760.

It is important to note that while this method provides a valid starting point, it does not guarantee the optimal solution. Therefore, in the following sections, we will evaluate the total transportation cost using two more refined methods:

- Least Cost Method (LCM)
- Vogel's Approximation Method (VAM)

These methods incorporate cost considerations during the allocation process and are likely to yield more cost-efficient solutions

Video: Transportation Problem – NWC Initial Allocation

Video: "[Transportation Models : North West Corner Initial Allocation](#)" by [Maths Resource](#) [8:45] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

11.7 LEAST COST METHOD

The Least Cost Method (LCM) is a more cost-conscious approach to generating an initial feasible solution for a balanced transportation model. Unlike the North-West Corner Method, LCM prioritizes allocations based on minimizing transportation costs from the outset.

Steps for Applying the Least Cost Method:

1. *Identify the Cell with the Lowest Transportation Cost:*
Scan the entire transportation tableau and locate the cell with the minimum unit cost.
2. *Allocate the Maximum Possible Quantity to This Cell:*
Assign as much as possible to the selected cell, based on the available supply and demand.
3. *Adjust Supply and Demand:*
Subtract the allocated quantity from the corresponding row (supply) and column (demand).
4. *Eliminate Satisfied Rows or Columns:*
If a row or column is fully satisfied (i.e., reduced to zero), it is crossed out or marked as complete.
5. *Repeat the Process:*
Continue selecting the next lowest-cost cell from the remaining tableau and repeat the allocation process until all supply and demand constraints are met.

This method typically results in a lower total transportation cost than the North-West Corner Method, as it incorporates cost efficiency into the allocation process from the beginning.



Example: Mega Farms Inc.

Mega Farms Inc. operates three strawberry farms (S1, S2, and S3) which supply four regional markets (D1, D2, D3, and D4). The supply capacities and market demands are as follows:

- Supply Capacities:
 - S1: 60 cases
 - S2: 80 cases
 - S3: 100 cases
- Market Demands:
 - D1: 50 cases
 - D2: 70 cases
 - D3: 80 cases
 - D4: 40 cases

The transportation cost per case (in \$) from each farm to each market is provided in the following tableau:

	D1	D2	D3	D4	Supply
S1	\$6	\$2	\$14	\$8	60 Cases
S2	\$4	\$12	\$10	\$18	80 Cases
S3	\$16	\$6	\$6	\$4	100 Cases
Demand	50 Cases	70 Cases	80 Cases	40 Cases	

Mega Farms Inc. wants to determine how many cases should be sent from which farm to which market so that the total cost of transportation is minimized.

Determining the Total Transportation Cost Using the Least Cost Method

The model tableau is shown below:

	D1	D2	D3	D4	Supply
S1	\$6	\$2	\$14	\$8	60
S2	\$4	\$12	\$10	\$18	80
S3	\$16	\$6	\$6	\$4	100
Demand	50	70	80	40	

Step 1: Select the Cell with the Lowest Cost

- The cell with the Lowest Cost is (S1, D2) with a cost of \$2
- Allocate all 60 units from S1
- Update:
 - S1 supply exhausted
 - D2 remaining demand = $70 - 60 = 10$

	D1	D2	D3	D4	Supply
S1	\$6	(60) \$2	\$14	\$8	60 0
S2	\$4	\$12	\$10	\$18	80
S3	\$16	\$6	\$6	\$4	100
Demand	50	70 10	80	40	

Step 2: Next Lowest Cost

- There is a tie for the next lowest cost at \$4, (S2, D1) and (S3, D4)
 - Randomly select (S2, D1)
- Allocate 50 units (the full demand of D1)
- Update:
 - S2 remaining supply = $80 - 50 = 30$
 - D1 demand fulfilled

	D1	D2	D3	D4	Supply
S1	\$6	(60) \$2	\$14	\$8	0
S2	(50) \$4	\$12	\$10	\$18	80 30
S3	\$16	\$6	\$6	\$4	100
Demand	50 0	10	80	40	

Step 3: Next Lowest Cost

- Move to the Next Lowest Cost, (S3, D4), Cost = \$4
- Allocate 40 units (total demand of D4)
- Update:
 - S3 remaining supply = $100 - 40 = 60$
 - D4 demand fulfilled

	D1	D2	D3	D4	Supply
S1	\$6	(60) \$2	\$14	\$8	0
S2	(50) \$4	\$12	\$10	\$18	30
S3	\$16	\$6	\$6	(40) \$4	100 60
Demand	0	10	80	40 0	

Step 4: Next Lowest Cost

- There is another tie at \$6 (S3, D2) and (S3, D3)
 - Randomly select (S3, D3)
- Allocate 60 units exhausting S3
- Update:
 - S3 supply exhausted
 - D3 remaining demand = $80 - 60 = 20$

	D1	D2	D3	D4	Supply
S1	\$6	(60) \$2	\$14	\$8	0
S2	(50) \$4	\$12	\$10	\$18	30
S3	\$16	\$6	(60) \$6	(40) \$4	60 0
Demand	0	10	80 20	0	

Step 5: Next Lowest Cost

- The Next Lowest Cost is (S2, D3), Cost = \$10
- Allocate 20 units (remaining demand from D3)
- Update:
 - S2 remaining supply = $30 - 20 = 10$
 - D3 demand fulfilled

	D1	D2	D3	D4	Supply
S1	\$6	(60) \$2	\$14	\$8	0
S2	(50) \$4	\$12	(20) \$10	\$18	30 10
S3	\$16	\$6	(60) \$6	(40) \$4	0
Demand	0	10	20 0	0	

Step 6: Final Allocation

- The Final Allocation will be to (S2, D2), Cost = \$12
- Allocate the remaining 10 units
- Update:
 - S2 exhausted
 - D2 demand fulfilled

	D1	D2	D3	D4	Supply
S1	\$6	(60) \$2	\$14	\$8	0
S2	(50) \$4	(10) \$12	(20) \$10	\$18	10 0
S3	\$16	\$6	(60) \$6	(40) \$4	0
Demand	0	10 0	0	0	

After completing the allocation process using the Least Cost Method, all supply capacities have been fully utilized, and all market demands have been satisfied. This confirms that a feasible solution has been reached.

To compute the total transportation cost, we multiply the quantity allocated to each cell by its corresponding unit transportation cost and sum the results:

$$\text{Total Cost} = (S2/D1 \times 4) + (S1/D2 \times 2) + (S2/D2 \times 12) + (S2/D3 \times 10) + (S3/D3 \times 6) + (S3/D4 \times 4)$$

$$\text{Total Cost} = (50 \times 4) + (60 \times 2) + (10 \times 12) + (20 \times 10) + (60 \times 6) + (40 \times 4)$$

$$\text{Total Cost} = 200 + 120 + 120 + 200 + 360 + 160$$

$$\text{Total Cost} = 1160$$

Thus, the initial basic feasible solution obtained using the Least Cost Method results in a total transportation cost of \$1160.

This solution is significantly more cost-efficient than the one obtained using the North-West Corner Method (\$1760), as it incorporates transportation costs into the allocation process. However, while this method often yields a near-optimal solution, it does not guarantee optimality.

Video: Transportation Problem – Least Cost Initial Allocation

Video: “[Transportation : Least Cost Initial Allocation](#)” by [Maths Resource](#) [5:51] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

To explore the possibility of further cost reduction, we now turn to Vogel’s Approximation Method (VAM)—a more refined approach that considers both cost and opportunity cost in its allocation strategy.

11.8 VOGEL'S APPROXIMATION METHOD

Vogel's Approximation Method (VAM) is a heuristic technique used to generate an initial feasible solution for a balanced transportation problem. It is widely regarded as one of the most effective initial allocation methods, as it incorporates both cost efficiency and opportunity cost into the decision-making process.

Steps for Applying VAM:

1. *Calculate Penalty Costs for Each Row and Column:*
For every row and column in the transportation tableau, compute the penalty by finding the difference between the two lowest unit transportation costs in that row or column. This penalty reflects the opportunity cost of not choosing the lowest-cost option.
2. *Identify the Row or Column with the Highest Penalty:*
Select the row or column with the largest penalty value. This indicates where the cost of making a suboptimal allocation would be greatest.
3. *Allocate to the Lowest-Cost Cell in the Selected Row or Column:*
Within the selected row or column, allocate as much as possible to the cell with the lowest transportation cost, based on the available supply and demand.
4. *Adjust Supply and Demand and Eliminate Satisfied Rows or Columns:*
Update the tableau by subtracting the allocated quantity and crossing out any row or column where supply or demand has been fully met.
5. *Recalculate Penalties and Repeat:*
Recompute the penalties for the remaining rows and columns and repeat the process until all supply and demand constraints are satisfied.

This method typically results in a lower total transportation cost than both the North-West Corner and Least Cost methods, making it a preferred choice for generating high-quality initial solutions.



Example: Mega Farms Inc.

Mega Farms Inc. operates three strawberry farms, (S1, S2, and S3), which supply four regional markets (D1, D2, D3, and D4). The supply capacities and market demands are as follows:

- Supply Capacities:
 - S1: 60 cases
 - S2: 80 cases
 - S3: 100 cases
- Market Demands:
 - D1: 50 cases
 - D2: 70 cases
 - D3: 80 cases
 - D4: 40 cases

The transportation cost per case (in \$) from each farm to each market is provided in the following tableau:

	D1	D2	D3	D4	Supply
S1	\$6	\$2	\$14	\$8	60 Cases
S2	\$4	\$12	\$10	\$18	80 Cases
S3	\$16	\$6	\$6	\$4	100 Cases
Demand	50 Cases	70 Cases	80 Cases	40 Cases	

Mega Farms Inc. wants to determine how many cases should be sent from which farm to which market so that the total cost of transportation is minimized.

Determining the Total Transportation Cost Using Vogel's Approximation Method (VAM)

	D1	D2	D3	D4	Supply
S1	\$6	\$2	\$14	\$8	60 Cases
S2	\$4	\$12	\$10	\$18	80 Cases
S3	\$16	\$6	\$6	\$4	100 Cases
Demand	50 Cases	70 Cases	80 Cases	40 Cases	

Step 1: Calculate Row and Column Penalties

The first step in Vogel's Approximation Method is to compute the penalty values for each row and column. These penalties represent the opportunity cost of not choosing the lowest-cost allocation in a given row or column. The penalty is calculated as the difference between the two lowest unit transportation costs in each row or column.

Row Penalties:

- S1: $6 - 2 = 4$
- S2: $10 - 4 = 6$
- S3: $6 - 4 = 2$

Column Penalties:

- D1: $6 - 4 = 2$
- D2: $6 - 2 = 4$
- D3: $10 - 6 = 4$
- D4: $8 - 4 = 4$

Step 2: Select the Row or Column with the Highest Penalty

Among all the calculated penalties, the highest is 6, which corresponds to row S2. This indicates that failing to allocate to the lowest-cost cell in this row would result in the greatest cost inefficiency.

- The lowest-cost cell in row S2 is (S2/D1), with a unit transportation cost of \$4.

Allocation:

- Allocate the minimum of the available supply and demand:
 - 50 units to satisfy the demand D1

Update:

- S2 supply is reduced to 30 units, $80 - 50 = 30$
- D1 demand is fully satisfied, and the column is eliminated from further consideration

	D1	D2	D3	D4	Supply	Row Difference
S1	\$6	\$2	\$14	\$8	60	4
S2	(50) \$4	\$12	\$10	\$18	80 30	6
S3	\$16	\$6	\$6	\$4	100	2
Demand	50 0	70	80	40		
Column Difference	2	4	4	4		

Step 3: Recalculate Penalties (Excluding Column D1)

With D1 now fully satisfied and removed from the tableau, we recalculate the penalty values for the remaining rows and columns.

Updated Row Penalties:

- S1: $8 - 2 = 6$
- S2: $12 - 10 = 2$
- S3: $6 - 4 = 2$

Updated Column Penalties:

- D2: $6 - 2 = 4$
- D3: $10 - 6 = 4$
- D4: $8 - 4 = 4$

Step 4: Select the Row or Column with the Highest Penalty

The highest penalty is 6, corresponding to row S1. This indicates that failing to allocate to the lowest-cost cell in this row would result in the greatest cost inefficiency.

- The lowest-cost cell in row S1 is (S1/D2), with a unit transportation cost of \$2.

Allocation:

- Allocate the minimum of the available supply and demand:
 - The minimum is the supply of 60 units

Update:

- S1 supply is now exhausted: $60 - 60 = 0$
- D2 demand is partially fulfilled: $70 - 60 = 10$

Row S1 is now eliminated from further consideration

	D1	D2	D3	D4	Supply	Row Difference 2	Row Difference 1
S1	6	(60) 2	14	8	60 0	6	4
S2	(50) 4	12	10	18	30	2	6
S3	16	6	6	4	100	2	2
Demand	0	70 10	80	40			
Column Difference 2		4	4	4			
Column Difference 1	2	4	4	4			

Step 5: Recalculate Penalties (Excluding Row S1 and Column D1)

With S1 and D1 now eliminated from the tableau, we recalculate the penalty values for the remaining rows and columns.

Updated Row Penalties:

- S2: $12 - 10 = 2$
- S3: $6 - 4 = 2$

Updated Column Penalties:

- D2: $12 - 6 = 6$
- D3: $10 - 6 = 4$
- D4: $18 - 4 = 14$

Step 6: Select the Row or Column with the Highest Penalty

The highest penalty is 14, corresponding to column D4. This indicates that failing to allocate to the lowest-cost cell in this column would result in the greatest cost inefficiency.

- The lowest-cost cell in column D4 is (S3/D4), with a unit transportation cost of \$4.

Allocation:

- Allocate the minimum of the available supply and demand:
 - The minimum is 40 units from D4

Update:

- S3 supply is reduced to $100 - 40 = 60$ units
- D4 demand is fully satisfied, and the column is removed from further consideration

	D1	D2	D3	D4	Supply	Row Difference 3	Row Difference 2	Row Difference 1
S1	6	(60) 2	14	8	0		6	4
S2	(50) 4	12	10	18	30	2	2	6
S3	16	6	6	(40) 4	100 60	2	2	2
Demand	0	10	80	40 0				
Column Difference 3		6	4	14				
Column Difference 2		4	4	4				
Column Difference 1	2	4	4	4				

Step 7: Recalculate Penalties (Excluding S1, D1, and D4)

With row S1 and columns D1 and D4 now eliminated from the tableau, we recalculate the penalty values for the remaining rows and columns.

Updated Row Penalties:

- S2: $12 - 10 = 2$
- S3: $6 - 6 = 0$

Updated Column Penalties:

- D2: $12 - 6 = 6$
- D3: $10 - 6 = 4$

Step 8: Select the Row or Column with the Highest Penalty

The highest penalty is 6, corresponding to column D2. This indicates that failing to allocate to the lowest-cost cell in this column would result in the greatest cost inefficiency.

- The lowest-cost cell in column D2 is (S3/D2), with a unit transportation cost of \$6.

Allocation:

- Allocate the minimum of the remaining supply and demand:
 - The minimum is 10 units to satisfy D2

Update:

- S3 supply is reduced to: $60 - 10 = 50$ units
- D2 demand is now fully satisfied, and the column is removed from further consideration

	D1	D2	D3	D4	Supply	Row Difference 4	Row Difference 3	Row Difference 2	Row Difference 1
S1	6	(60) 2	14	8	0			6	4
S2	(50) 4	12	10	18	30	2	2	2	6
S3	16	(10) 6	6	(40) 4	60 50	0	2	2	2
Demand	0	10 0	80	0					
Column Difference 4		6	4						
Column Difference 3		6	4	14					
Column Difference 2		4	4	4					
Column Difference 1	2	4	4	4					

Final Allocation: Completing the Tableau

At this stage, only two unallocated cells remain—one in each of the remaining rows (S2 and S3) and one column (D3). Since no further penalty calculations are meaningful with only one option per row and column, we proceed directly with the final allocations.

Final Allocations:

- Allocate 50 units to (S3/D3)
 - Remaining supply at S3: $50 - 50 = 0$
 - Remaining demand at D3: $80 - 50 = 30$
- Allocate 30 units to (S2/D3)
 - Remaining supply at S2: $30 - 30 = 0$
 - Remaining demand at D3: $30 - 30 = 0$

Result:

- All supplies are exhausted
- All market demands are fully satisfied

This completes the initial feasible solution using Vogel's Approximation Method.

	D1	D2	D3	D4	Supply	Row Difference 4	Row Difference 3	Row Difference 2	Row Difference 1
S1	6	(60) 2	14	8	0			6	4
S2	(50) 4	12	(30) 10	18	30 0	2	2	2	6
S3	16	(10) 6	(50) 6	(40) 4	50 0	0	2	2	2
Demand	0	0	80 30 0	0					
Column Difference 4		6	4						
Column Difference 3		6	4	14					
Column Difference 2		4	4	4					
Column Difference 1	2	4	4	4					

After completing all allocations using Vogel's Approximation Method, the total transportation cost is calculated as follows:

$$\text{Total Cost} = (S2/D1 \times 4) + (S1/D2 \times 2) + (S3/D2 \times 6) + (S2/D3 \times 10) + (S3/D3 \times 6) + (S3/D4 \times 4)$$

$$\text{Total Cost} = (50 \times 4) + (60 \times 2) + (10 \times 6) + (30 \times 10) + (50 \times 6) + (40 \times 4)$$

$$\text{Total Cost} = 200 + 120 + 60 + 300 + 300 + 160$$

$$\text{Total Cost} = 1140$$

Thus, the initial basic feasible solution obtained using VAM results in a total transportation cost of \$1140, which is lower than the \$1160 obtained using the Least Cost Method and significantly better than the \$1760 from the North-West Corner Method.

This outcome highlights one of the key advantages of VAM: it often produces a more cost-effective initial solution by incorporating both transportation costs and opportunity costs into the allocation process.

However, it is important to note that even though VAM typically yields a near-optimal solution, it does not guarantee optimality. In the following sections, we will explore optimization techniques

Video: Vogel Approximation Method

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11.9 FINDING THE OPTIMAL SOLUTION: MINIMIZING TOTAL TRANSPORTATION COST

A **basic feasible solution**, such as those obtained through the North-West Corner Method, Least Cost Method, or Vogel's Approximation Method, serves as a starting point in solving a transportation problem. However, these methods do not guarantee optimality. To determine whether further cost reduction is possible, we must assess whether the current solution can be improved.

Step 1: Degeneracy Check

Before proceeding with optimization, it is essential to verify that the solution is non-degenerate. A transportation model is considered non-degenerate if the number of basic allocations equals (number of rows + number of columns – 1). If this condition is not met, the solution is degenerate, and special handling is required before optimization can proceed.

Step 2: Optimization Techniques

If the solution passes the degeneracy test, we can proceed to identify the optimal solution using one of the following methods:

- **Stepping Stone Method:**

A trial-and-error approach that evaluates the opportunity cost of unused routes to determine whether reallocating shipments can reduce total cost.

- **Modified Distribution Method (MODI or UV Method):**

A more systematic and efficient technique that uses dual variables (U and V) to compute opportunity costs and identify potential improvements.

- **Linear Programming (LP):**

A mathematical formulation of the transportation problem that can be solved using the Simplex Method or specialized LP solvers.

These optimization methods will be explored in detail in the following sections, with step-by-step illustrations and examples.

Testing for Degeneracy in a Basic Feasible Solution

In the context of transportation models, a basic feasible solution is said to be degenerate if it does not contain the minimum required number of positive allocations to maintain a unique and solvable structure.

Degeneracy Condition:

Let:

- r = number of supply points (rows)
- c = number of demand points (columns)
- N = number of positive (non-zero) allocations in the solution

Then:

- If $N = r + c - 1$, the solution is non-degenerate and can proceed directly to optimization.
- If $N < r + c - 1$, the solution is degenerate, and special adjustments (such as introducing a very small allocation, often denoted by ϵ) are required to proceed with optimization methods like MODI or Stepping Stone.

Degeneracy can lead to computational difficulties or incorrect results if not properly addressed. Therefore, it is essential to perform this check before attempting to optimize any initial feasible solution.



Example

The model reflects a retail firm that supplies its stores in three cities through three DCs as shown in the following tableau.

	M1	M2	M3	Supply
DC1	6	9	16	200
DC2	11	10	7	200
DC3	16	12	10	200
Demand	150	200	250	

Using the basic feasible solution, the firm's current transportation cost is:

	M1	M2	M3	Supply
DC1	(150) 6	(50) 9	16	0
DC2	11	(150) 10	(50) 7	0
DC3	16	12	(200) 10	0
Demand	0	0	0	

The total transportation cost based on the current allocation:

$$\text{Total Cost} = (150 \times 6) + (50 \times 9) + (150 \times 10) + (50 \times 7) + (200 \times 20)$$

$$\text{Total Cost} = \$5200$$

This represents the total cost of the current basic feasible solution. The firm now seeks to determine whether this solution is **optimal** or if further cost reductions are possible.

Step 1: Degeneracy Testing

To assess whether the solution can be optimized, we must first test for degeneracy.

Let:

- N = number of basic (non-zero) allocations = 5
- r = number of supply points (rows) = 3
- c = number of demand points (columns) = 3

According to the degeneracy condition:

$$\begin{aligned} N &= r + c - 1 \\ &= 3 + 3 - 1 \\ &= 5 \end{aligned}$$

Since $N=r+c-1$, the solution is **non-degenerate**, and we can proceed with optimization using methods such as the **Modified Distribution Method (MODI)** or the **Stepping Stone Method**.

Finding the Optimal Solution Using the Stepping Stone Method

The Stepping Stone Method is a systematic approach used to evaluate whether a basic feasible solution to a transportation problem can be improved. It does so by analyzing the impact of introducing a shipment into an unoccupied (empty) cell and tracing a closed loop through the tableau to assess the net change in total cost.

Despite the term “loop,” the structure formed is not circular in shape. Instead, it consists of a sequence of horizontal and vertical moves that connect occupied cells, forming a closed path that begins and ends at the same unoccupied cell.

Let us apply the Stepping Stone Method to our example. The following tableau illustrates one such loop identified in the initial solution.

	M1	M2	M3	Supply
DC1	(150) 6	(50) 9	16	0
DC2	11	(150) 10	(50) 7	0
DC3	16	12	(200) 10	0
Demand	0	0	0	

Steps in the Stepping Stone Method:

1. *Identify All Unoccupied Cells:*

These are the potential candidates for improvement. Each unoccupied cell represents a possible new shipping route.

2. *Construct a Closed Loop for Each Unoccupied Cell:*

Starting from the unoccupied cell, trace a path through alternating horizontal and vertical moves, connecting only occupied cells, and return to the starting point. The loop must alternate between adding and subtracting units.

3. *Calculate the Net Cost Change for the Loop:*

Assign alternating plus (+) and minus (-) signs to the cells in the loop, starting with a plus at the unoccupied cell. Then compute the net change in cost by summing the products of unit costs and their respective signs.

4. *Evaluate All Loops:*

- If all net cost changes are zero or positive, the current solution is optimal.
- If any net cost change is negative, the solution can be improved. Select the loop with the most negative net cost, adjust the allocations accordingly, and repeat the process.

	M1	M2	M3	Supply
DC1	(150) 6	(50) 9	16	0
DC2	11	-1 (150) 10	+1 (50) 7	0
DC3	16	+1 12	-1 (200) 10	0
Demand	0	0	0	

This method provides a clear and intuitive way to test for optimality and iteratively improve the solution. In the next section, we will demonstrate this process step-by-step using our transportation example.

In the previous tableau, we evaluated the opportunity cost of assigning a shipment to the unoccupied cell (D3/M2). The net cost change associated with this cell was -1 , indicating a potential opportunity to reduce the total transportation cost by reallocating shipments through a closed loop.

Interpreting the Negative Opportunity Cost

A negative value (-1) suggests that the current solution could be improved by assigning units to the unoccupied cell (D3/M2). To explore this possibility, we construct a closed loop involving this cell and other occupied cells, following the Stepping Stone procedure.

Loop Construction:

The loop formed is as follows:

$$(D3/M2) \rightarrow (D2/M2) \rightarrow (D2/M3) \rightarrow (D3/M3)$$

This loop includes the following cells:

- (D3/M2) (unoccupied, starting point)
- (D2/M2) (occupied)
- (D2/M3) (occupied)
- (D3/M3) (occupied)

Allocation Adjustments:

We apply alternating $+1$ and -1 adjustments along the loop:

- +150 units to (D3/M2) (introducing a new shipment)
- −150 units from (D2/M2) (removing the same quantity)
- +150 units to (D2/M3) (reallocating supply)
- −150 units from (D3/M3) (reducing the original allocation)

This reallocation maintains the supply and demand balance while potentially reducing the total cost.

Updated Allocations:

- (D3/M2): $0 \rightarrow 150$
- (D2/M2): $150 \rightarrow 0$
- (D2/M3): $50 \rightarrow 200$
- (D3/M3): $200 \rightarrow 50$

	M1	M2	M3	Supply
DC1	(150) 6	(50) 9	16	0
DC2	11	(150 0) 10	(50 200) 7	0
DC3	16	(150) 12	(200 50) 10	0
Demand	0	0	0	

New Total Transportation Cost:

$$\text{Total Cost} = (150 \times 6) + (50 \times 9) + (0 \times 10) + (200 \times 7) + (150 \times 12) + (50 \times 10)$$

$$\text{Total Cost} = (900) + (450) + (0) + (1400) + (1800) + (500)$$

$$\text{Total Cost} = \$5,050$$

This revised solution results in a **reduced transportation cost of \$5,050**, compared to the original \$5,200—confirming that the previous solution was not optimal.



Video: Transportation Method Stepping Stone

Video: “[Transportation Method stepping stone](#)” by [Professor Dansereau](#) [6:13] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Finding the Optimal Solution Using the Modified Distribution (MODI) Method

The Modified Distribution Method (MODI) is a powerful optimization technique used to evaluate and improve a basic feasible solution in a transportation model. It relies on the use of dual variables—denoted as U_i for rows and V_j for columns—to calculate the opportunity cost of unoccupied cells and determine whether the current solution is optimal. Let us apply the MODI method to the previously discussed transportation model.

Step 1: Assign Dual Variables U_i and V_j

For each **occupied cell** (i.e., a cell with a positive allocation), the cost C_{ij} must satisfy the condition:

$$C_{ij} = U_i + V_j$$

We begin by arbitrarily setting one of the dual variables to zero. Let $U_1 = 0$. Using the occupied cells, we solve for the remaining U_i and V_j values.

		V1	V2	V3	
		D1	D2	D3	
U1	S1	(150) 6	(50) 9	16	0
U2	S2	11	(150) 10	(50) 7	0
U3	S3	16	12	(200) 10	0
		0	0	0	

From the allocations:

$$U1 = 0$$

$$(S1/D1) = V1 + U1$$

$$6 = V1 + 0$$

$$V1 = 6$$

$$(S1/D2) = V2 + U1$$

$$9 = V1 + 0$$

$$V1 = 9$$

$$(S2/D2) = V2 + U2$$

$$10 = 9 + U2$$

$$U2 = 10 - 9$$

$$U2 = 1$$

$$(S2/D3) = V3 + U2$$

$$7 = V3 + 1$$

$$V3 = 7 - 1$$

$$V3 = 6$$

$$(S3/D3) = V3 + U3$$

$$10 = 6 + U3$$

$$U3 = 10 - 6$$

$$U3 = 4$$

Final Values:

- $U1 = 0$
- $U2 = 1$
- $U3 = 4$
- $V1 = 6$

- $V_2 = 9$
- $V_3 = 6$

Step 2: Calculate Opportunity Costs for Unoccupied Cells

For each unoccupied cell, compute the **opportunity cost**:

$$d_{ij} = C_{ij} - (U_i + V_j)$$

$$d_{13} = 16 - (6 + 0)$$

$$d_{13} = 16 - 6$$

$$d_{13} = 10$$

$$d_{21} = 11 - (1 + 6)$$

$$d_{21} = 11 - 7$$

$$d_{21} = 4$$

$$d_{31} = 16 - (4 + 6)$$

$$d_{31} = 16 - 10$$

$$d_{31} = 6$$

$$d_{32} = 12 - (4 + 9)$$

$$d_{32} = 12 - 13$$

$$d_{32} = -1$$

Step 3: Check for Optimality

If all $d_{ij} \geq 0$, the current solution is optimal.

However, since $d_{32} = -1$, the solution is **not optimal**, and there is an opportunity to reduce the total cost by reallocating shipments.

Step 4: Improve the Solution via Pivoting

We construct a **closed loop** starting at the most negative cell, (S3/D2), and apply alternating + and – adjustments along the loop:

		Markets				
Distribtuion		V1 = 6	V2 = 9	V3 = 6		
		D1	D2	D3	Supply	
	U1 = 0	S1	(150) 6	(50) 9	16	200
	U2 = 1	S2	11	-1 (150) 10	+1 (50) 7	200
	U3 = 4	S3	16	+1 12	-1 (200) 10	200
		Demand	150	200	250	

Loop:

$(S3/D2) (+) \rightarrow (S2/D2) (-) \rightarrow (S2/D3) (+) \rightarrow (S3/D3) (-)$

Revised Allocations:

- $(S3/D2): 0 \rightarrow 150$
- $(S2/D2): 150 \rightarrow 0$
- $(S2/D3): 50 \rightarrow 200$
- $(S3/D3): 200 \rightarrow 50$

Updated Total Transportation Cost:

Total Cost = $(150 \times 6) + (50 \times 9) + (0 \times 10) + (200 \times 7) + (150 \times 12) + (50 \times 10)$

Total Cost = $900 + 450 + 0 + 1400 + 1800 + 500$

Total Cost = 5,050

This confirms that the MODI method leads to the same improved solution previously obtained using the Stepping Stone Method, validating its effectiveness and accuracy



Video: Transportation Problem Optimal Solution with MODI Method

Video: “[Transportation Problem Optimal Solution with MODI Method](#)” by [Professor Dansereau](#) [3:58] is licensed under the [Standard YouTube License](#). Transcript and closed captions available on YouTube.

Finding the Optimal Solution Using Linear Programming

The transportation problem can also be formulated and solved as a Linear Programming Problem (LPP). This approach provides a rigorous mathematical framework for minimizing transportation costs while satisfying all supply and demand constraints.

	M1	M2	M3	Supply
DC1	(X_{11}) 6	(X_{12}) 9	(X_{13}) 16	200
DC2	(X_{21}) 11	(X_{22}) 10	(X_{23}) 7	200
DC3	(X_{31}) 16	(X_{32}) 12	(X_{33}) 10	200
Demand	150	200	250	

Decision Variables

Let X_{ij} represent the quantity of goods transported from supply point i (e.g., a distribution center) to demand point j (e.g., a market). Each X_{ij} must be **non-negative**:

$$X_{ij} \geq 0 \text{ for all } i, j$$

Objective Function

The goal is to minimize the total transportation cost, which is the sum of the products of unit costs and the corresponding decision variables:

$$\text{Minimize } Z = 6X_{11} + 9X_{12} + 16X_{13} + 11X_{21} + 10X_{22} + 7X_{23} + 16X_{31} + 12X_{32} + 10X_{33}$$

Constraints

The model must satisfy both supply constraints (each source cannot ship more than its available supply) and demand constraints (each destination must receive its required quantity):

Supply Constraints:

$$X_{11} + X_{12} + X_{13} \leq 200 \text{ Supply from S1}$$

$$X_{21} + X_{22} + X_{23} \leq 200 \text{ Supply from S2}$$

$$X_{31} + X_{32} + X_{33} \leq 200 \text{ Supply from S3}$$

Demand Constraints:

$$X_{11} + X_{21} + X_{31} \leq 150 \text{ Demand from D1}$$

$$X_{12} + X_{22} + X_{32} \leq 200 \text{ Demand from D2}$$

$$X_{13} + X_{23} + X_{33} \leq 200 \text{ Demand from D3}$$

This formulation captures the essence of the transportation problem as a linear program. The solution to this LPP will yield the optimal allocation of shipments that minimizes total cost while respecting all constraints.

A detailed explanation of how to solve linear programming problems using methods such as the Simplex Method or software-based solvers is provided in the next chapter, [Chapter 12: Linear Programming](#).

11.10 CHAPTER SUMMARY & REVIEW



Chapter Summary

This chapter introduces transportation models as a quantitative tool used to minimize the cost of distributing goods from multiple supply points to multiple demand points. These models rely on clearly defined elements, including supply capacities at sources, demand requirements at destinations, unit transportation costs, and decision variables that represent shipment quantities. A distinction is made between balanced models (where supply equals demand) and unbalanced models (where a mismatch exists). Unbalanced problems are converted into balanced ones by introducing dummy supply or demand nodes, allowing for the application of standard solution techniques. Initial feasible solutions can be generated using methods such as the North-West Corner Rule, the Least Cost Method, and Vogel's Approximation Method (VAM), each with different levels of efficiency in minimizing costs.

While these initial solutions ensure feasibility, they may not be optimal. Therefore, optimization techniques such as the Stepping Stone Method and the Modified Distribution (MODI) Method are applied to refine allocations and further reduce total costs. The chapter also emphasizes the need to check for degeneracy, which can disrupt optimization, and demonstrates how the problem can be formulated as a linear programming problem for more advanced solutions. Case studies demonstrate practical applications of these methods, illustrating how businesses can significantly reduce logistics expenses by strategically allocating shipments. Ultimately, transportation models enable organizations to meet market demand efficiently while maintaining cost competitiveness.

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Exercises

1. Define a transportation model and explain its main components.

Solution

A transportation model is a specialized form of a linear programming problem designed to determine the most cost-efficient way to distribute goods from multiple supply points (e.g., factories or distribution centres) to multiple demand points (e.g., retail outlets or markets), while satisfying supply and demand constraints.

Main Components:

- **Supply Points:**

Locations where goods are available for shipment. Each supply point has a fixed supply capacity.

- **Demand Points:**

Locations where goods are required. Each demand point has a specific demand that must be fulfilled.

- **Transportation Costs:**

The unit cost of transporting goods from each supply point to each demand point. These costs form the basis of the objective function to be minimized.

- **Decision Variables:**

Represent the quantity of goods shipped from the supply point to the demand point. These are the variables to be determined in the optimization process.

2. What is the difference between a balanced and an unbalanced transportation model? How can an unbalanced model be converted to a balanced one?

Solution

Balanced Transportation Model:

A transportation model is **balanced** when the total supply equals the total demand:

$$\sum Supply = \sum Demand$$

This condition ensures that all goods can be distributed without surplus or shortage.

Unbalanced Transportation Model:

A model is **unbalanced** when:

- **Total Supply $\neq$ Total Demand**

This can occur in two ways:

- **Supply exceeds demand:** There is surplus capacity.
- **Demand exceeds supply:** There is a shortfall in available goods.

Balancing an Unbalanced Model:

To convert an unbalanced model into a balanced one:

- **If Supply < Demand:**
Introduce a **dummy demand point** with demand equal to the surplus. Assign zero transportation cost from all supply points to this dummy destination.
- **If Demand > Supply:**
Introduce a **dummy supply point** with supply equal to the shortfall. Assign zero transportation cost from this dummy source to all demand points.

This transformation ensures that the model satisfies the balance condition, allowing it to be solved using standard transportation algorithms.

3. Transportation Problem: Initial Feasible Solution Using the North-West Corner Method

A company operates two warehouses and serves three markets. The supply, demand, and unit transportation costs are as follows:

	M1	M2	M3	Supply
W1	4	6	8	100
W2	5	3	7	150
Demand	80	120	50	250

- Is this problem balanced?
- Find an initial feasible solution using the North West Corner method.
- Calculate the total transportation cost for your solution.

Solution

a. **Is the problem balanced?**

- **Total Supply** = 100 (W1) + 150 (W2) = 250 units
- **Total Demand** = 80 (M1) + 120 (M2) + 50 (M3) = 250 units. Yes, the problem is balanced.

b. **Initial Feasible Solution Using the North-West Corner Method**
Step-by-step allocation:

- (W1/M1):** Remaining: 20 units; M1 satisfied
- (W1/M2):** Allocate $\min(20, 120) = 20$ units
→ W1 exhausted; M2 remaining: 100 units
- (W2/M2):** Allocate $\min(150, 100) = 100$ units
→ W2 remaining: 50 units; M2 satisfied
- (W2/M3):** Allocate $\min(50, 50) = 50$ units
→ W2 exhausted; M3 satisfied

c. **Total Transportation Cost**

- (W1/M1): $80 \times 4 = 320$
- (W1/M2): $20 \times 6 = 120$

- (W2/M2): $100 \times 3 = 300$
- (W2/M3): $50 \times 7 = 350$
- Total Cost: $320 + 120 + 300 + 350 = \$1,090$

4. Applying the Least Cost Method

Solution

Method Overview:

The Least Cost Method generates an initial feasible solution by prioritizing allocations to the **lowest-cost cells** first. The steps are:

1. Identify the cell with the **lowest transportation cost**.
2. Allocate as much as possible to that cell.
3. Adjust supply and demand; eliminate satisfied rows or columns.
4. Repeat with the next lowest-cost cell.

Application to the Problem:

1. (W2/M2) (Cost = 3):
Allocate $\min(150, 120) = 120$ units
→ W2 remaining: 30; M2 satisfied
2. (W1/M1) (Cost = 4):
Allocate $\min(100, 80) = 80$ units
→ W1 remaining: 20; M1 satisfied
3. (W2/M3) (Cost = 7):
Allocate $\min(30, 50) = 30$ units
→ W2 exhausted; M3 remaining: 20
4. (W1/M3) (Cost = 8):
Allocate the remaining 20 units
→ W1 exhausted; M3 satisfied

Total Transportation Cost

- (W2/M2): $120 \times 3 = 360$
- (W1/M1): $80 \times 4 = 320$
- (W2/M3): $30 \times 7 = 210$
- (W1/M3): $20 \times 8 = 160$

$$\text{Total Cost: } 360 + 320 + 210 + 160 = \$1,050$$

The Least Cost Method yields a **lower total cost** than the North-West Corner Method, demonstrating its efficiency in generating a more cost-effective initial solution.

5. What is Vogel's Approximation Method (VAM), and why does it often yield a better initial solution?

Solution

Vogel's Approximation Method (VAM) is a heuristic used to generate an initial feasible solution for a transportation problem. It improves cost efficiency by incorporating the concept of **opportunity cost** into the allocation process.

Steps:

1. For each row and column, calculate the **penalty**: the difference between the two lowest transportation costs.
2. Identify the row or column with the **highest penalty**.
3. Allocate as much as possible to the **lowest-cost cell** in that row or column.
4. Adjust supply and demand, eliminate satisfied rows/columns, and repeat the process.

By considering the cost of not choosing the next-best alternative, VAM often produces a **lower total transportation cost** than simpler methods like the North-West Corner or Least Cost Method.

6. How do you test a transportation model solution for degeneracy, and why is it important?

Solution

A transportation solution is degenerate if the number of positive allocations **N** is **less than $r + c - 1$** , where:

- r = number of supply points (rows)
- c = number of demand points (columns)

Degeneracy Test:

- If $N = r + c - 1$: the solution is **non-degenerate** and suitable for optimization.
- If $N < r + c - 1$: the solution is **degenerate** and must be adjusted (e.g., by inserting a zero allocation in an unoccupied cell) to proceed with optimization.

Importance:

Degeneracy can disrupt optimization methods like **Stepping Stone or MODI**, which rely on a specific number of basic variables. Testing ensures the solution structure is valid for further improvement.

7. A transportation problem has 3 supply points and 4 demand points. What is the minimum number of positive allocations required in a non-degenerate solution?

Solution

Minimum number of positive allocations = $r + c - 1 = 3 + 4 - 1 = \mathbf{6}$

8. Explain the Stepping Stone Method and its role in finding the optimal transportation solution.

Solution

The **Stepping Stone Method** is an optimization technique used to evaluate whether a current transportation solution can be improved.

How it works:

- For each **unoccupied cell**, construct a **closed loop** by connecting it to occupied cells through horizontal and vertical moves.
- Assign alternating + and – signs to the loop cells and calculate the **net cost change**.
- If the net cost is **negative**, reallocating along the loop will reduce the total cost.

This process is repeated until **no negative net costs remain**, indicating that the **optimal solution** has been reached.

9. In the Mega Farms example, what were the total transportation costs obtained by the three initial solution methods? Which method gave the lowest cost?

Solution

- **North-West Corner Method:** \$1,760
- **Least Cost Method:** \$1,160
- **Vogel's Approximation Method (VAM):** \$1,140

VAM produced the **lowest total transportation cost**, demonstrating its effectiveness in generating a near-optimal initial solution.

10. Why might an initial feasible solution not be optimal, and what methods can be used to optimize it?

Solution

Initial feasible solutions are constructed using **allocation rules** that do not necessarily minimize total cost. As a result, they may overlook more efficient shipping routes.

Optimization Methods:

- **Stepping Stone Method:** Evaluates unoccupied cells for potential cost-saving reallocations.
- **Modified Distribution Method (MODI):** Uses dual variables to systematically assess opportunity costs and guide reallocation.

These methods refine the initial solution to achieve the **minimum possible transportation cost**, ensuring true optimality

11.11 CASE STUDIES



Case Study 1: Aqua Fresh Spring Water

Aqua Fresh has established a distribution network for the supply of spring water critical to its bottling plants. Currently, there are two springs for water, which must be shipped to three bottling plants. The current distribution network is shown below:

Transportation Costs/Bottle

(Spring to Plants)	Plant 1	Plant 2	Plant 3	Spring Output
Spring 1 (West Mountain Range)	\$6	\$8	\$9	400 Bottles
Spring 2 (East Mountain Range)	\$4	\$7	\$3	600 Bottles
Bottling Plant Intake Capacity	500 Bottles	500 Bottles	500 Bottles	

The company has identified two potential sites for a third spring in the central mountain range; these are identified as Candidate A and Candidate B. From A, the costs to ship would be \$9 to Plant 1, \$10 to Plant 2, and \$12 to Plant 3. From B, these costs would be \$11, \$14, and \$8. The new spring, wherever it is located, will have a capacity of 500 units.

Tasks

(a) Expand the Distribution Network

Construct a transportation model that includes each candidate spring (A and B) as a

third source. Represent the network using a transportation tableau for each scenario (i.e., one with Candidate A and one with Candidate B).

(b) Determine the Optimal Spring Location

Using transportation cost minimization techniques (e.g., the Transportation Simplex Method or software-based optimization), identify which candidate spring — A or B — should be selected to minimize total transportation costs.

(c) Evaluate Further Cost Reduction Opportunities

Analyze whether the total transportation cost, after selecting the optimal spring, can be further reduced. Consider possibilities such as:

- Reallocating supply among springs
- Adjusting plant intake capacities
- Introducing multi-modal transport or bulk discounts



Case Study 2: All Mats Services – Optimizing Delivery Logistics

Refer to the All Mats Services case in [Chapter 5](#). The company completes a variety of mat orders daily, which are shipped using a fleet of three trucks. The trucks differ in capacity, cost efficiency, and delivery range. The current shipping process assigns orders to any available truck without a structured cost-minimization strategy.

Truck Fleet and Operational Details

Truck Type	Capacity (Orders/Day)	Cost per Rubber Mat/Runner Job (USD)	Cost per Plush Job (USD)	Special Notes
10-footer	36	\$16	\$12	Local deliveries only
15-footer	56	\$16	\$20	Local deliveries only
20-footer	76	\$18	\$22	Can handle out-of-town deliveries

Currently, the company assigns orders to trucks randomly, without considering cost implications.

Tasks

(a) Estimate the Current Cost of Random Shipping

Assuming a random allocation of orders across the three trucks, calculate the expected daily shipping cost. Consider the mix of rubber mat/runner jobs and plush jobs in your analysis.

(b) Identify Opportunities for Cost Reduction

Can the current shipping cost be reduced through a more strategic allocation of orders to trucks? If so, determine the new optimized shipping cost using appropriate optimization techniques (e.g., linear programming or cost minimization models).

(c) Determine the Absolute Minimum Shipping Cost

Is the cost calculated in part (b) the lowest possible? If not, identify the absolute minimum shipping cost and describe the optimal allocation strategy that achieves it.

11.12 KEY TERMS



Key Terms

- **Balanced Transportation Model:** A transportation model where total supply equals total demand.
- **Basic Feasible Solution:** A starting solution obtained through methods like NWCM, LCM, or VAM, satisfying supply and demand but not necessarily optimal.
- **Center of Gravity Method:** A location strategy for finding the optimal position of a DC to minimize transportation costs.
- **Cost Minimization:** The primary objective in transportation models is to reduce total shipping cost while meeting all constraints.
- **Decision Variable:** Represents the quantity of goods to be transported from a specific supply point to a demand point.
- **Degeneracy:** Occurs when the number of positive allocations in a basic solution is less than $(\text{rows} + \text{columns} - 1)$, potentially complicating optimization.
- **Demand Point:** A destination location (e.g., market or retail outlet) where goods are needed.
- **Dummy Demand Point:** An artificial demand point added to balance excess supply, with zero transportation cost.
- **Dummy Supply Point:** An artificial supply point added to balance excess demand, with zero transportation cost.
- **Least Cost Method (LCM):** An initial solution method that allocates units to the cell with the lowest transportation cost.
- **Linear Programming (LP):** A mathematical approach to optimize a linear objective function subject to constraints.

- **Modified Distribution Method (MODI):** Also called the UV method, this optimization technique calculates opportunity costs using dual variables.
- **North-West Corner Method (NWCM):** A basic method for finding an initial feasible solution that starts in the top-left cell of the tableau.
- **occupied cell** (i.e., a cell with a positive allocation)
- **Opportunity Cost:** The potential increase or decrease in total cost associated with reallocating supply.
- **Optimal Solution:** The allocation of goods that results in the lowest total transportation cost.
- **Stepping Stone Method:** An iterative technique for improving an initial solution by evaluating potential cost-saving re-routes using loops.
- **Supply Point:** A source location (e.g., factory or distribution center) from which goods are shipped.
- **Transportation Cost:** The cost per unit to transport goods from a supply point to a demand point.
- **Transportation Model:** A type of linear programming problem focused on minimizing the cost of shipping goods from multiple supply points to multiple demand points.
- **Transportation Network:** A configuration of multiple supply and demand points connected through shipping routes.
- **Transportation Tableau:** A matrix used to represent transportation problems, showing supply, demand, and costs.
- **Unbalanced Transportation Model:** A model where total supply does not equal total demand; requires adjustment through dummy points.
- **Vogel's Approximation Method (VAM):** A heuristic that uses penalties (opportunity costs) to guide initial allocations and often yields near-optimal solutions.

CHAPTER 12: LINEAR PROGRAMMING

Chapter Outline

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12.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- List the key parts of a linear programming problem, like the goal, variables, and limits.
- Describe how linear programming helps businesses make the best use of their resources.
- Use the graphical method to solve a problem with two variables and find the best solution.
- Compare the graphical method and the Simplex method to see when each one works best.
- Verify that a solution from Excel Solver is correct by reviewing the results and ensuring it adheres to all the rules.
- Create a linear programming model from a real-world example and solve it using a method you've learned.

12.1 OPTIMIZING RESOURCES FOR BUSINESS EFFICIENCY

Introduction to Linear Programming in Business

Linear Programming (LP) is a fundamental mathematical optimization technique used to determine the best possible outcome, such as maximizing profit or minimizing cost, subject to a set of linear constraints. These constraints typically represent limitations in resources such as time, labour, or capital.

LP is widely applied across various disciplines, including:

- Production planning and scheduling
- Transportation and logistics
- Financial portfolio optimization
- Healthcare resource allocation
- Network flow optimization

In the context of business decision-making, LP serves as a strategic tool for optimizing resource utilization and improving operational efficiency.

The Business Motivation: Profit Maximization

A central objective of most business enterprises is to maximize profit. Profit (π) can be expressed as the difference between Total Revenue (TR) and Total Cost (TC):

$$\pi = TR - TC$$

Expanding this further:

$$\pi = \text{Price} \times Q - (\text{Fixed Cost} + \text{Variable Cost}(Q))$$

Where:

- Q is the quantity of goods or services produced,
- Fixed Costs (FC) are independent of output,
- Variable Costs (VC) vary with the level of output.

Thus, profit can be increased by:

- Maximizing total revenue, or
- Minimizing total cost

However, both strategies are constrained by the availability of resources. This necessitates the use of optimization techniques, such as linear programming, to make the most effective use of limited inputs.

Components of a Linear Programming Problem (LPP)

To apply LP in a business context, the real-world scenario must be translated into a mathematical model known as a Linear Programming Problem (LPP). The key components of an LPP are:

1. **Objective Function:** A linear function representing the goal of the problem (e.g., maximize profit or minimize cost).
2. **Decision Variables:** The unknowns to be determined (e.g., quantities of products to produce).
3. **Constraints:** A set of linear inequalities or equations that represent resource limitations.
4. **Non-negativity Constraints:** Decision variables are typically required to be non-negative, as negative quantities are not feasible in most business contexts.

Standard Form of an LPP

An LPP in standard form is written as:

Maximize (or Minimize):

$$Z = c_1x_1 + c_2x_2 + \dots + c_nx_n$$

Subject to:

$$a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \leq b_1$$

$$a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \leq b_2$$

$$\vdots$$

$$a_{m1}x_1 + a_{m2}x_2 + \dots + a_{mn}x_n \leq b_m$$

$$x_1, x_2, \dots, x_n \geq 0$$

Methods for Solving LPPs

Once formulated, an LPP can be solved using one of the following methods:

- **Graphical Method:** Suitable for problems involving two decision variables. It provides a visual representation of the feasible region and optimal solution.
- **Simplex Method:** A systematic algebraic approach capable of solving problems with multiple variables and constraints.



Illustrative Example: Maximizing Bakery Profit

Scenario: Marietta owns a bakery that produces a variety of baked goods. For special orders, she bakes biscuits and cupcakes, earning a profit of \$5 per biscuit and \$4 per cupcake. Each biscuit requires 3 minutes in the mixer and 4 minutes in the oven, while each cupcake requires 5 minutes in the mixer and 1 minute in the oven. Due to other production commitments, she has only 78 minutes of mixer time and 36 minutes of oven time available for special orders.

Objective: Determine the number of biscuits and cupcakes Marietta should bake to maximize her profit.

Step 1: Define Decision Variables

Let:

- x_1 = number of biscuits
- x_2 = number of cupcakes

Step 2: Formulate the Objective Function

Maximize $Z = 5x_1 + 4x_2$

Step 3: Define the Constraints

Mixer time constraint:

$$3x_1 + 5x_2 \leq 78$$

Oven time constraint:

$$4x_1 + x_2 \leq 36$$

Non-negativity constraints:

$$x_1, x_2 \geq 0$$

This formulation represents a complete LPP. The next step would be to solve it using either the graphical method (since there are two variables) or the simplex method.

12.2 SOLVING THE LPP USING THE GRAPHICAL METHOD

To solve the formulated **Linear Programming Problem (LPP)** graphically, we begin by converting the inequality constraints into equations. This allows us to plot the boundary lines that define the feasible region.

Given the constraints:

$$3x_1 + 5x_2 = 78 \text{ (Mixer time)}$$

$$4x_1 + x_2 = 36 \text{ (Oven time)}$$

These equations can be represented graphically by identifying their intercepts with the axes and drawing the corresponding lines. This is illustrated in Figure 12.2.1, which shows the boundary lines for the mixer and oven constraints.

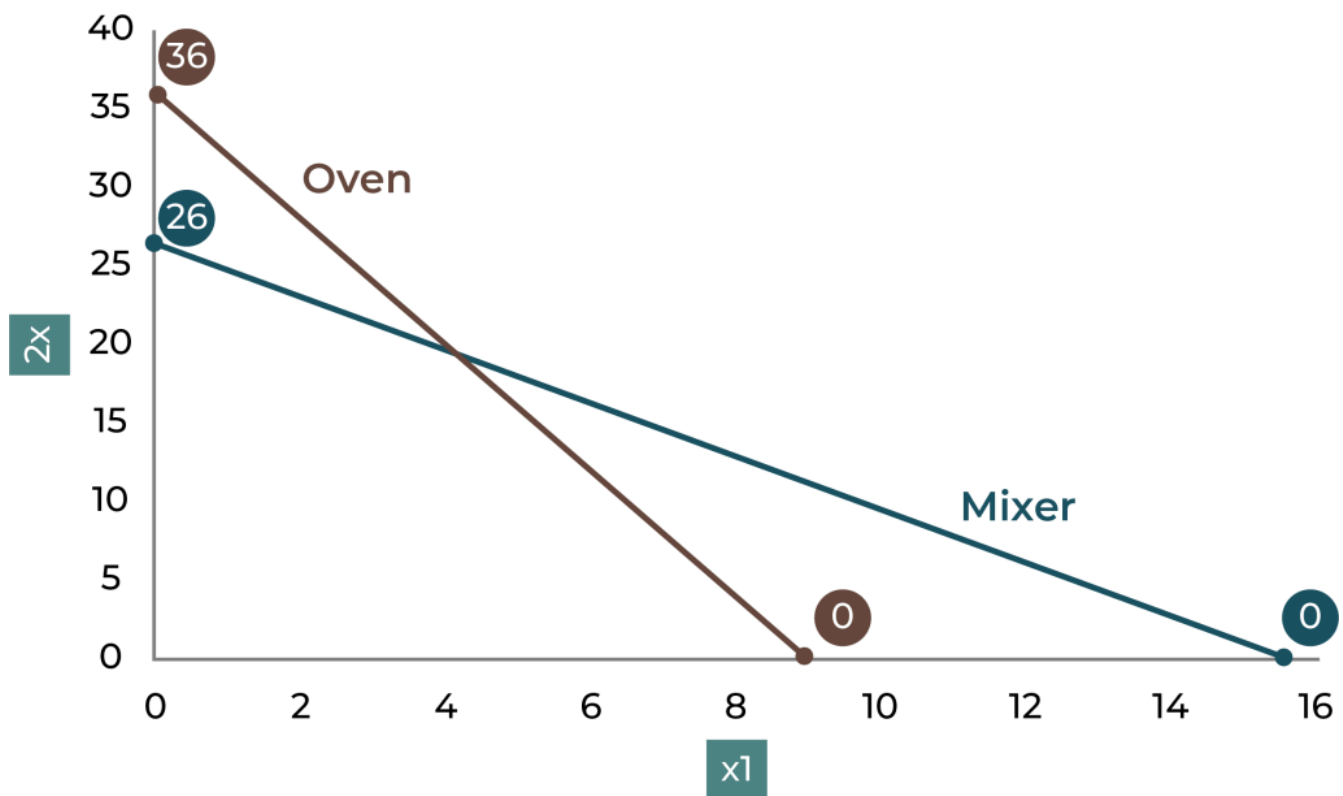


Figure 12.2.1: Graphical representation of the constraint equations (mixer and oven time)

However, since the original constraints are inequalities:

$$3x_1 + 5x_2 \leq 78$$

$$4x_1 + x_2 \leq 36$$

We must consider not only the lines themselves but also the regions they bound. The feasible region includes all points that satisfy both inequalities simultaneously. This region is typically shaded on the graph.

In Figure 12.2.2, the individual constraint regions are shown in light brown and teal, while their intersection, representing the feasible region, is highlighted in grey.

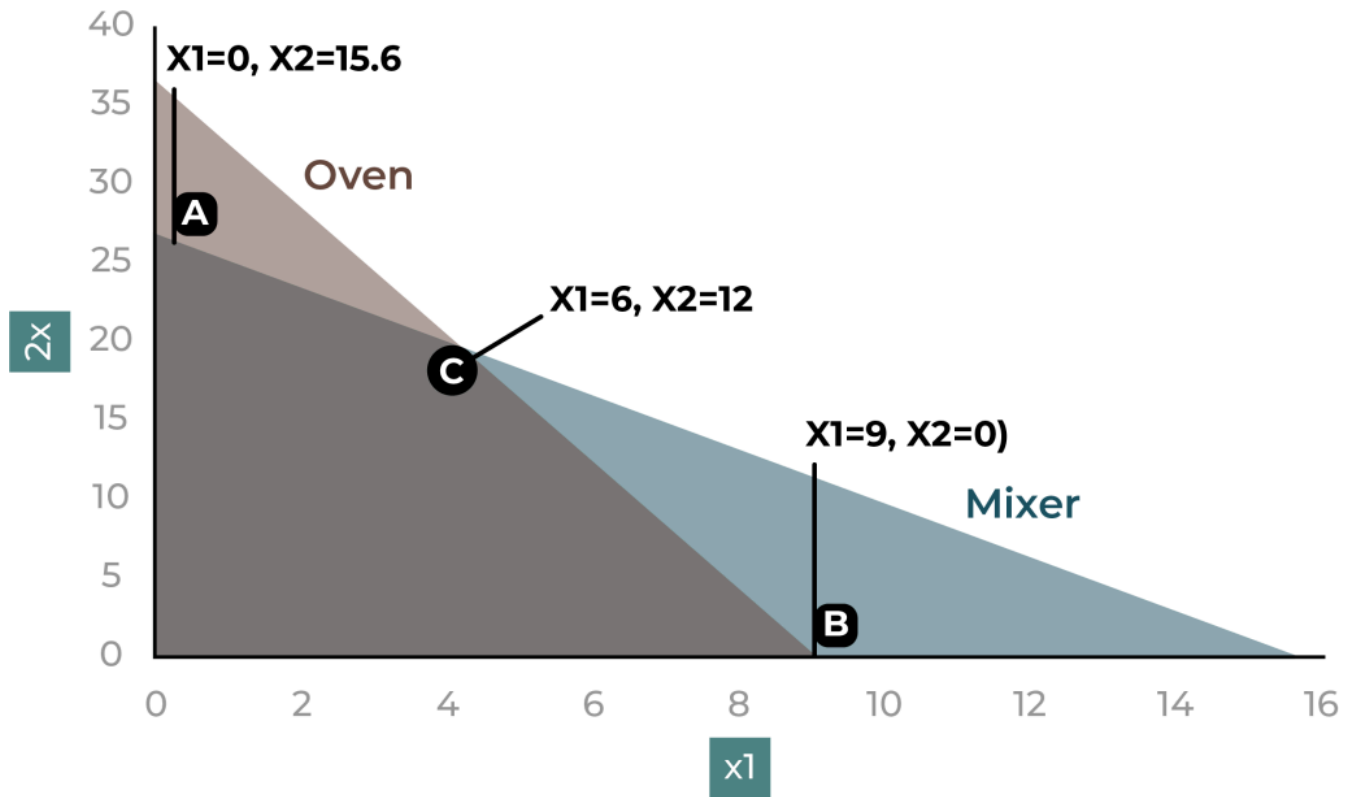


Figure 12.2.2. The feasible region is formed by the intersection of constraint inequalities

The feasible region contains all combinations of x_1 (biscuits) and x_2 (cupcakes) that satisfy the resource constraints. Any point within this region is a potential solution. However, our goal is to *maximize the objective function*:

$$Z = 5x_1 + 4x_2$$

To do this, we evaluate the objective function at the **corner points** (vertices) of the feasible region. These points represent the optimal candidates due to the convex nature of the feasible region in linear programming.

- **Point A:** $x_1 = 0, x_2 = 15.6$ (maximum cupcakes, no biscuits)
- **Point B:** $x_1 = 9, x_2 = 0$ (maximum biscuits, no cupcakes)
- **Point C:** Intersection of the two constraint lines (both x_1 and x_2 are non-zero)

To find the coordinates of **Point C**, we solve the system of equations:

$$3x_1 + 5x_2 = 78$$

$$4x_1 + x_2 = 36$$

Solving this system yields the exact values of x_1 and x_2 at the intersection point, which is likely to provide the optimal solution.

Hint:

$$3x_1 + 5x_2 = 78$$

$$4x_1 + 1x_2 = 36$$

Multiply both sides of the second equation by -5 to eliminate x_2

$$3x_1 + 5x_2 = 78$$

$$4x_1 + x_2 = 36$$

$$-5(4x_1 + x_2) = -5(36)$$

$$-20x_1 - 5x_2 = -180$$

$$3x_1 + 5x_2 = 78$$

$$-20x_1 - 5x_2 = -180$$

$$(3x_1 + 5x_2) + (-20x_1 - 5x_2) = 78 + (-180)$$

$$-17x_1 = -102$$

$$x_1 = 6$$

Substituting x_1 value in any of the two equations, we will multiply both sides of the second equation by -5 to eliminate x_2

Evaluating the Objective Function at Corner Points

Once the coordinates of the corner points (A, B, and C) of the feasible region have been identified, the next step is to evaluate the **objective function** at each of these points to determine which one yields the maximum profit.

The objective function is:

$$Z = 5x_1 + 4x_2$$

We now substitute the values of x_1 and x_2 at each point:

At Point A

$$(x_1 = 0, x_2 = 15.6)$$

$$\begin{aligned} Z &= 5(0) + 4(15.6) \\ &= 62.4 \end{aligned}$$

At Point B

$$(x_1 = 9, x_2 = 0)$$

$$\begin{aligned} Z &= 5(9) + 4(0) \\ &= 45 \end{aligned}$$

At Point C

$$(x_1 = 6, x_2 = 12)$$

$$\begin{aligned} Z &= 5(6) + 4(12) \\ &= 30 + 48 \\ &= 78 \end{aligned}$$

The maximum profit of \$78 is achieved at Point C, where Marietta should produce 6 biscuits and 12 cupcakes. This combination makes the most efficient use of her available mixer and oven time while maximizing her special-order profit.

12.3 SOLVING THE LPP USING THE SIMPLEX METHOD

The **Simplex Method** is a systematic, tabular approach used to solve linear programming problems involving more than two variables or when a graphical solution is impractical. It iteratively improves the solution by moving from one vertex (corner point) of the feasible region to another, in search of the optimal value of the objective function.

Step 1: Represent the Problem in Tabular Form

We begin by organizing the coefficients of the objective function and constraints into a matrix format:

	Biscuit (x_1)	Cupcake (x_2)	RHS (Resources)
Objective (Z)	5	4	–
Mixer	3	5	78
Oven	4	1	36

This corresponds to the original problem:

$$\text{Maximize: } Z = 5 \times 1 + 4 \times 2$$

Subject to:

$$3 \times 1 + 5 \times 2 \leq 78 \quad \text{Mixer constraint}$$

$$4 \times 1 + 1 \times 2 \leq 36 \quad \text{Oven constraint}$$

$$x_1, x_2 \geq 0$$

Step 2: Convert Inequalities to Equations

To apply the Simplex Method, we convert the inequalities into equalities by introducing **slack variables**:

- Let u be the slack variable for the mixer constraint
- Let w be the slack variable for the oven constraint

The constraints become:

$$3 \times 1 + 5 \times 2 + u = 78$$

$$4 \times 1 + 1 \times 2 + w = 36$$

The initial simplex tableau is then constructed by bringing all terms to the left-hand side and expressing the objective function in standard form (with negative coefficients):

Basic Variable	x_1	x_2	u	w	RHS
Z	-5	-4	0	0	0
u	3	5	1	0	78
w	4	1	0	1	36

Step 3: Iterative Optimization

The Simplex Method proceeds by performing pivot operations to eliminate negative values in the objective row. Each iteration improves the value of the objective function by selecting:

- The entering variable (the most negative coefficient in the objective row)
- The leaving variable (determined by the minimum ratio test)

This process continues until there are no negative values in the objective row, indicating that the optimal solution has been reached. The following video illustrates the steps of the simplex method to solve our LPP.

Video: Transportation Problem – NWC Initial Allocation

Video: “[Simplex Method, Example 1](#)” by [Dr D’s Math Help](#) [7:44] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

12.4 SOLVING A LINEAR PROGRAMMING PROBLEM (LPP) USING EXCEL SOLVER

In addition to the Simplex Method, the Linear Programming Problem (LPP) can also be solved using **Excel Solver**, a powerful optimization tool available in Microsoft Excel. Below, we outline the step-by-step process for formulating and solving the LPP in Excel.

Step 1: Formulate the LPP in Excel

Consider the following LPP:

Figure 12.4.1 LPP

	Biscuit (x_1)	Cupcakes (x_2)	
Objective	5	4	Z
Mixer	3	5	78
Oven	4	1	36
Solution (x_1, x_2)	0	0	

Step 2: Define the Objective Function

Initially, we enter 0 for both decision variables (x_1 and x_2) in the solution row. The objective function is defined using the **SUMPRODUCT** function in Excel:

	A	B	C	D	E	F	G
1		Biscuit (x1)	C. Cakes (X2)				
2	Objective	5	4				
3	Mixer	3	5			78	
4	Oven	4	1			36	
5	Solution	0	0				

Figure 12.4.2 Excel Screenshot. © Microsoft.

12.4.2 Image Description

A Microsoft Excel spreadsheet displays a table used for linear programming or resource allocation, comparing the production of Biscuits (x_1) and Cakes (x_2). The table includes rows labelled “Objective,” “Mixer,” “Oven,” and “Solution.”

- The “Objective” row lists the profit per unit: 5 for Biscuits and 4 for Cakes.
- The “Mixer” row shows the resource requirements: 3 for Biscuits and 5 for Cakes, with a constraint of 78 (in cell F2).
- The “Oven” row shows requirements: 4 for Biscuits and 1 for Cakes, with a constraint of 36 (in cell F3).
- The “Solution” row currently contains zeros for both products.

Coloured cells highlight different resource rows, likely for visual differentiation purposes. Columns are labelled from B to F.

Once the solution is obtained, the initial zero values assigned to the decision variables x_1 and x_2 will be replaced by non-negative optimal values. It is important to understand that these variables serve as coefficients in the **SUMPRODUCT** function, which calculates the objective function and the left-hand sides of the constraints.

To enable Excel Solver to process the LPP correctly, the relationship between the decision variables and the objective function must be explicitly defined. This is done by entering a SUMPRODUCT formula in the objective cell (e.g., cell D2), which multiplies the values of x_1 and x_2 (from the solution range) by their corresponding objective coefficients.

For example, the formula might look like this:

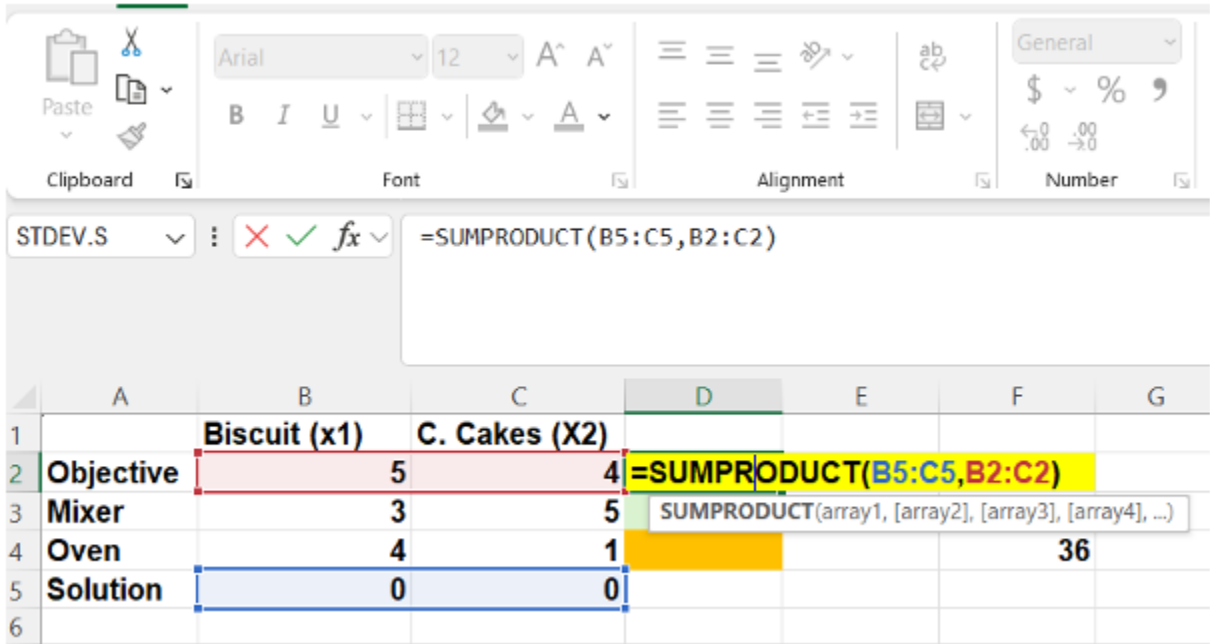


Figure 12.4.3 Excel Screenshot. © Microsoft.

12.4.3 Image Description

A Microsoft Excel spreadsheet shows a formula being entered in cell D5: `=SUMPRODUCT (B5 : C5 , B2 : C2 )` . The table compares two products: Biscuits (x_1) and Cakes (x_2), with rows for “Objective,” “Mixer,” “Oven,” and “Solution.” The formula highlights the “Solution” row (B5:C5) and the “Objective” row (B2:C2), indicating a dot product to calculate total profit. The calculated result, 36, appears in cell G4 (corresponding to the Oven constraint). The formula bar and syntax helper are also visible, and cells are colour-coded for clarity: red for the “Objective” row, blue for the “Solution” row, and yellow for the formula cell.

In this formula:

- The *blue-highlighted* cell references (e.g., `$B$5:$C$5`) represent the solution range (i.e., the decision variables).
- The *red-highlighted* cell references (e.g., `B2:C2`) represent the objective function coefficients.

The use of absolute references (with dollar signs) ensures that the solution range remains fixed when the formula is copied to other cells, such as those used to compute the constraint expressions.

	A	B	C	D	E	F	G
1		Biscuit (x1)	C. Cakes (X2)				
2	Objective	5	4	=SUMPRODUCT(\$B\$5:\$C\$5, B2:C2)			
3	Mixer	3	5	SUMPRODUCT(array1, [array2], [array3], [array4], ...)			
4	Oven	4	1				36
5	Solution	0	0				
6							

Figure 12.4.4 Excel Screenshot. © Microsoft.

12.4.4 Image Description

An Excel spreadsheet shows the formula `=SUMPRODUCT ($B$5 : $C$5 , B2 : C2 )` entered in cell D2, highlighted in yellow. The formula multiplies the values in the “Solution” row (row 5, cells B5 and C5, shown in blue) with the “Objective” coefficients (row 2, cells B2 and C2, shown in red) to calculate a total value. The dollar signs in `$B$5 : $C$5` indicate absolute references. The SUMPRODUCT function is displayed in the formula bar with its syntax hint below. The table tracks inputs for Biscuits (x1) and Cakes (x2) and includes rows for Objective, Mixer, Oven, and Solution. The result “36” is displayed in cell G4.

After entering the formula, press Enter. At this stage, the Linear Programming Problem (LPP) in Excel will reflect the initial setup. The value displayed in the objective cell (e.g., cell D2) will be zero. This result is expected, as it represents the SUMPRODUCT of the initial decision variable values (both set to zero) and their corresponding objective function coefficients (5 and 4). Since any number multiplied by zero yields zero, the objective function currently evaluates to zero.

	A	B	C	D	E	F	G
1		Biscuit (x1)	C. Cakes (X2)				
2	Objective	5	4	0			
3	Mixer	3	5			78	
4	Oven	4	1			36	
5	Solution	0	0				

Figure 12.4.5 Excel Screenshot. © Microsoft.

Figure 12.4.5 Image Description

An Excel spreadsheet displays a linear programming-style table used for resource allocation between two products: Biscuits (x_1) and Cakes (x_2). The rows include “Objective,” “Mixer,” “Oven,” and “Solution.”

- The “Objective” row shows the profit per unit: 5 for Biscuits and 4 for Cakes.
- The “Mixer” and “Oven” rows show the resource requirements for each product, with constraints of 78 and 36 listed in column F.
- The “Solution” row has zeros for both products ($x_1 = 0$, $x_2 = 0$).
- Cell D2 is highlighted yellow and contains the value 0, representing the calculated total objective value based on the solution (likely using the SUMPRODUCT function).
- Some cells in the “Mixer” and “Oven” rows are highlighted in gradient colours for visual emphasis.

Next, the formula entered in the objective cell (e.g., the yellow cell) should be copied to the cells corresponding to the constraint rows (e.g., the green and orange cells). This ensures that the left-hand side of each constraint is also calculated using the SUMPRODUCT of the decision variables and the respective constraint coefficients.

To do this, click on the bottom-right corner of the yellow cell (which contains the SUMPRODUCT formula) and drag it downward to cover the constraint rows. Since the current values of x_1 and x_2 are both zero, the resulting calculations in the constraint cells will also be zero. This is expected, as multiplying zero-valued decision variables by any coefficients yields zero.

This step confirms that the formulas are correctly replicated and that the structure of the model is consistent across the objective and constraint rows.

	A	B	C	D	E	F	G
1		Biscuit (x1)	C. Cakes (X2)				
2	Objective	5	4	0			
3	Mixer	3	5	0		78	
4	Oven	4	1	0		36	
5	Solution	0	0				
6							

Figure 12.4.6 Excel Screenshot. © Microsoft

12.4.6 Image Description

An Excel spreadsheet displays a resource allocation table for two products: Biscuits (x1) and Cakes (x2). The table includes rows labelled “Objective,” “Mixer,” “Oven,” and “Solution.”

- The “Objective” row shows profit per unit: 5 for Biscuits and 4 for Cakes.
- The “Mixer” row lists resource usage: 3 for Biscuits and 5 for Cakes, with a constraint of 78 in cell F3.
- The “Oven” row lists resource usage: 4 for Biscuits and 1 for Cakes, with a constraint of 36 in cell F4.
- The “Solution” row contains 0 units for both Biscuits and Cakes.
- Column D contains calculated values for each row, all currently 0 and filled with a yellow background, suggesting these are formula outputs (e.g., SUMPRODUCT calculations).
- The interface includes the Excel ribbon and a blank formula bar, with no formula currently selected.

To verify that the formulas have been correctly copied into the constraint rows, you can double-click on any of the corresponding cells. Doing so will highlight the cell references involved in the formula, allowing you to visually confirm that the correct rows and columns are being used in the SUMPRODUCT calculation.

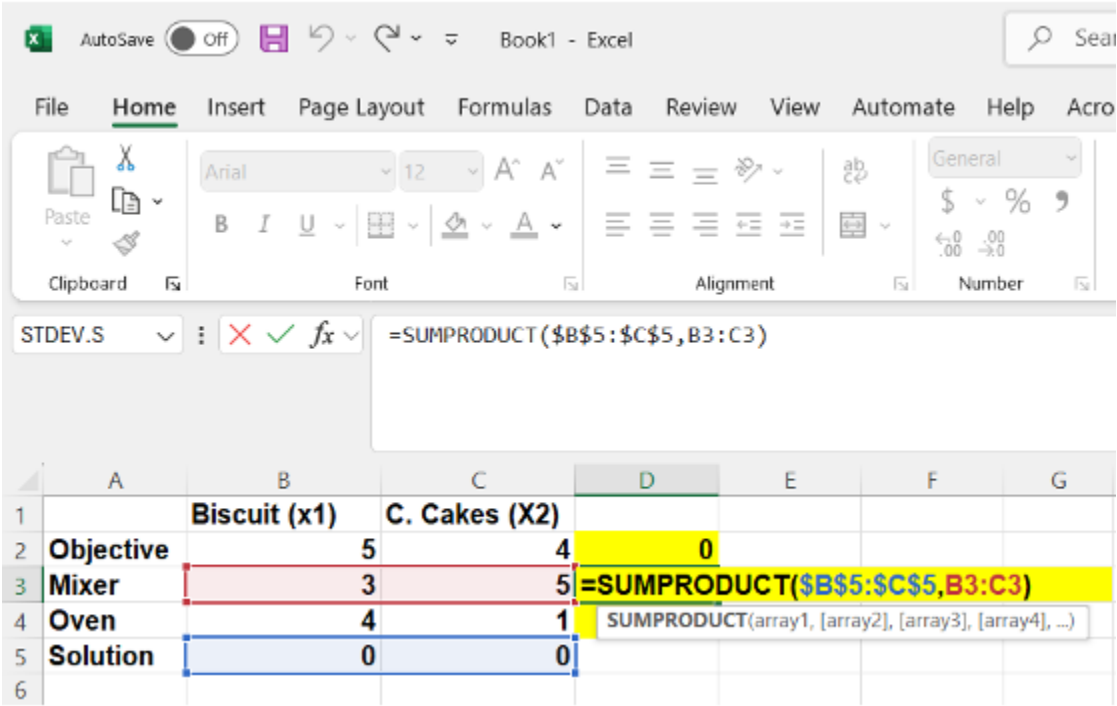


Figure 12.4.7 Excel Screenshot. © Microsoft

12.4.7 Image Description

An Excel spreadsheet shows a calculation using the SUMPRODUCT function in cell D3, highlighted in yellow. The formula is `=SUMPRODUCT ($B$5 : $C$5 , B3 : C3 )`, which multiplies values from the “Solution” row (row 5, shown in blue) with the corresponding values from the “Mixer” row (row 3, shown in red) for Biscuits (x1) and Cakes (x2). The result, currently 0, is displayed in cell D3. The table includes rows for Objective, Mixer, Oven, and Solution, and columns for product types. Resource constraints are listed in column F (78 for Mixer and 36 for Oven). The formula bar is visible at the top, with SUMPRODUCT syntax help displayed.

With all SUMPRODUCT formulas correctly defined and verified, the model is now ready to be solved using Excel Solver.

To access Solver, follow these steps:

1. Click on the Data tab located at the top of the Excel window.
2. In the Data ribbon, locate and click on Solver, typically found on the far right.¹
3. The Solver Parameters dialogue box will appear. For convenience, you may drag this dialogue box closer to your LPP model on the worksheet.

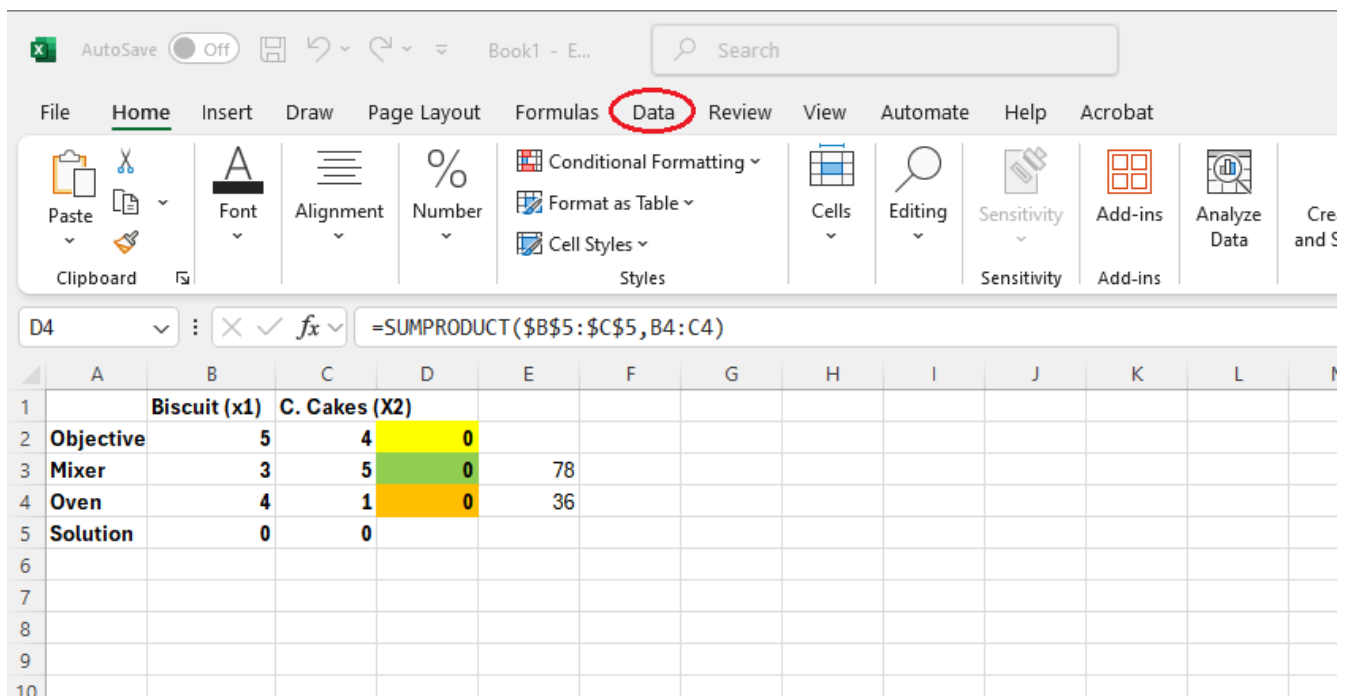


Image Description

Image 1: An Excel spreadsheet is open with a pop-up instruction pointing to the “Data” tab in the ribbon, which is circled in red. The instruction reads: “Click on the Data tab located at the top of the Excel window.”

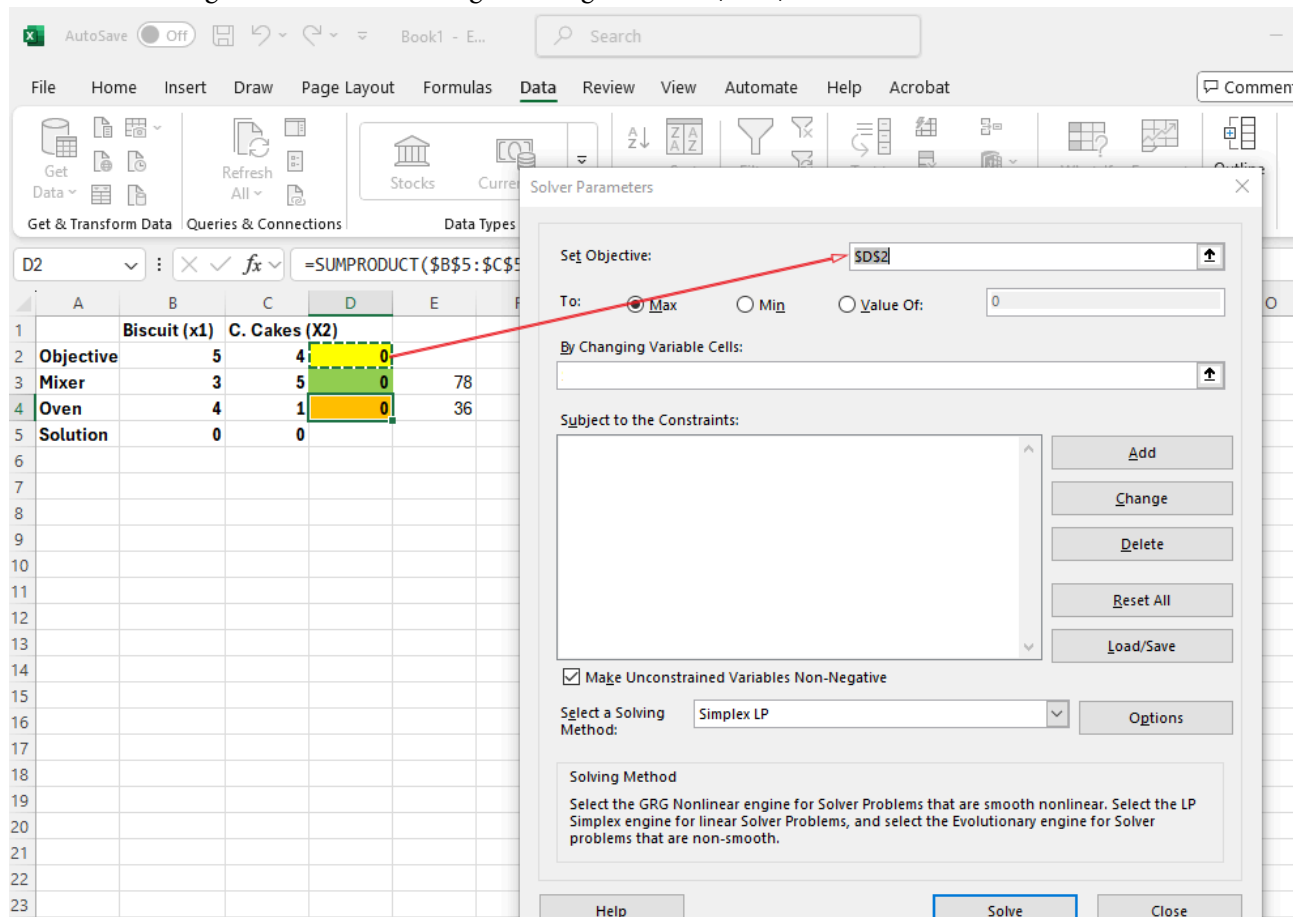
Image 2: An Excel spreadsheet is open with a highlighted instruction pointing to the “Solver” tool in the

1. Note: You might have to enable the Solver add-in with the following steps: 1. Go to File > Options. 2. Click Add-ins. 3. In the Manage box, select Excel Add-ins and click Go. 4. Check the Solver Add-in box and click OK

“Data” ribbon. A red circle emphasizes the “Solver” button on the far right of the ribbon. A text box says: “In the Data ribbon, locate and click on Solver, typically found on the far right.”

Image 3: An Excel spreadsheet is open with the “Solver Parameters” dialogue box displayed in the foreground. The dialogue box includes fields for setting the objective cell, selecting Max or Min, and specifying changing variable cells and constraints. A note on the spreadsheet reads: “The Solver Parameters dialogue box will appear. For convenience, you may drag this dialogue box closer to your LPP model.”

At this stage, the **Solver Parameters** dialogue box prompts you to input the necessary model components. Essentially, Solver requires you to define the objective function, specify the decision variables, and set the constraints that govern the Linear Programming Problem (LPP).



The screenshot shows the Excel Solver Parameters dialog box open over a spreadsheet. The spreadsheet contains a linear programming problem with the following data:

	Biscuit (x1)	C. Cakes (X2)	
Objective	5	4	0
Mixer	3	5	0
Oven	4	1	0
Solution	0	0	

The Solver Parameters dialog box is configured as follows:

- Set Objective:** \$D\$2
- To:** ☒ Max ☐ Min ☐ Value Of: 0
- By Changing Variable Cells:** (empty)
- Subject to the Constraints:** (empty list)
- ☒ Make Unconstrained Variables Non-Negative
- Select a Solving Method:** Simplex LP
- Solving Method:** Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

The **Solve** button is highlighted at the bottom of the dialog box.

The screenshot shows the Excel Solver Parameters dialog box open over a spreadsheet. The spreadsheet contains a linear programming problem with the following data:

	Biscuit (x1)	C. Cakes (X2)	
Objective	5	4	0
Mixer	3	5	0
Oven	4	1	0
Solution	0	0	

The Solver Parameters dialog box is configured as follows:

- Set Objective:** \$D\$2
- To:** ☒ Max ☐ Min ☐ Value Of: 0
- By Changing Variable Cells:** (empty)
- Subject to the Constraints:** (empty)
- ☒ Make Unconstrained Variables Non-Negative
- Select a Solving Method:** Simplex LP
- Solving Method:** Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

A red bracket highlights the 'Solution' row in the spreadsheet, and a red arrow points from it to the 'By Changing Variable Cells' field in the Solver Parameters dialog box.

The screenshot shows the Excel Solver Parameters dialog box open over a spreadsheet. The spreadsheet contains a linear programming problem for maximizing profit from Biscuits (x1) and Cakes (x2).

Spreadsheet Data:

	Biscuit (x1)	C. Cakes (x2)	
Objective	5	4	0
Mixer	3	5	0
Oven	4	1	0
Solution	0	0	

The formula bar shows: `=SUMPRODUCT($B$5:$C$5:D5:D5)`

Solver Parameters Dialog Box:

- Set Objective:** \$D\$2
- To:** ☒ Max ☐ Min ☐ Value Of: 0
- By Changing Variable Cells:** (empty)
- Subject to the Constraints:** (empty list)
- ☒ Make Unconstrained Variables Non-Negative
- Select a Solving Method:** Simplex LP
- Solving Method:** Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

The **Add** button in the constraints section is circled in red.

Excel interface showing the Solver setup for a Linear Programming Problem (LPP). The Data tab is active, and the Solver Parameters dialog box is open.

Excel Formulas Bar: $=\text{SUMPRODUCT}(\$B\$5:\$C\$5, B4:C4)$

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Biscuit (x1)	C. Cakes (X2)										
2	Objective	5	4	0									
3	Mixer	3	5	0	78								
4	Oven	4	1	0	36								
5	Solution	0	0										

Add Constraint Dialog Box:

Cell Reference: Constraint: $\leq$

Buttons: OK, Add, Cancel

Excel interface showing the Solver Parameters dialog box. The formula bar displays $=\text{SUMPRODUCT}(\$B\$5:\$C\$5, B4:C4)$.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Biscuit (x1)	C. Cakes (X2)										
2	Objective	5	4	0									
3	Mixer	3	5	0	78								
4	Oven	4	1	0	36								
5	Solution	0	0										

The Solver Parameters dialog box is open, showing the "Add Constraint" section. The "Cell Reference" field is empty, and the "Constraint" field is empty. The "Constraint" dropdown menu is set to $\leq$.

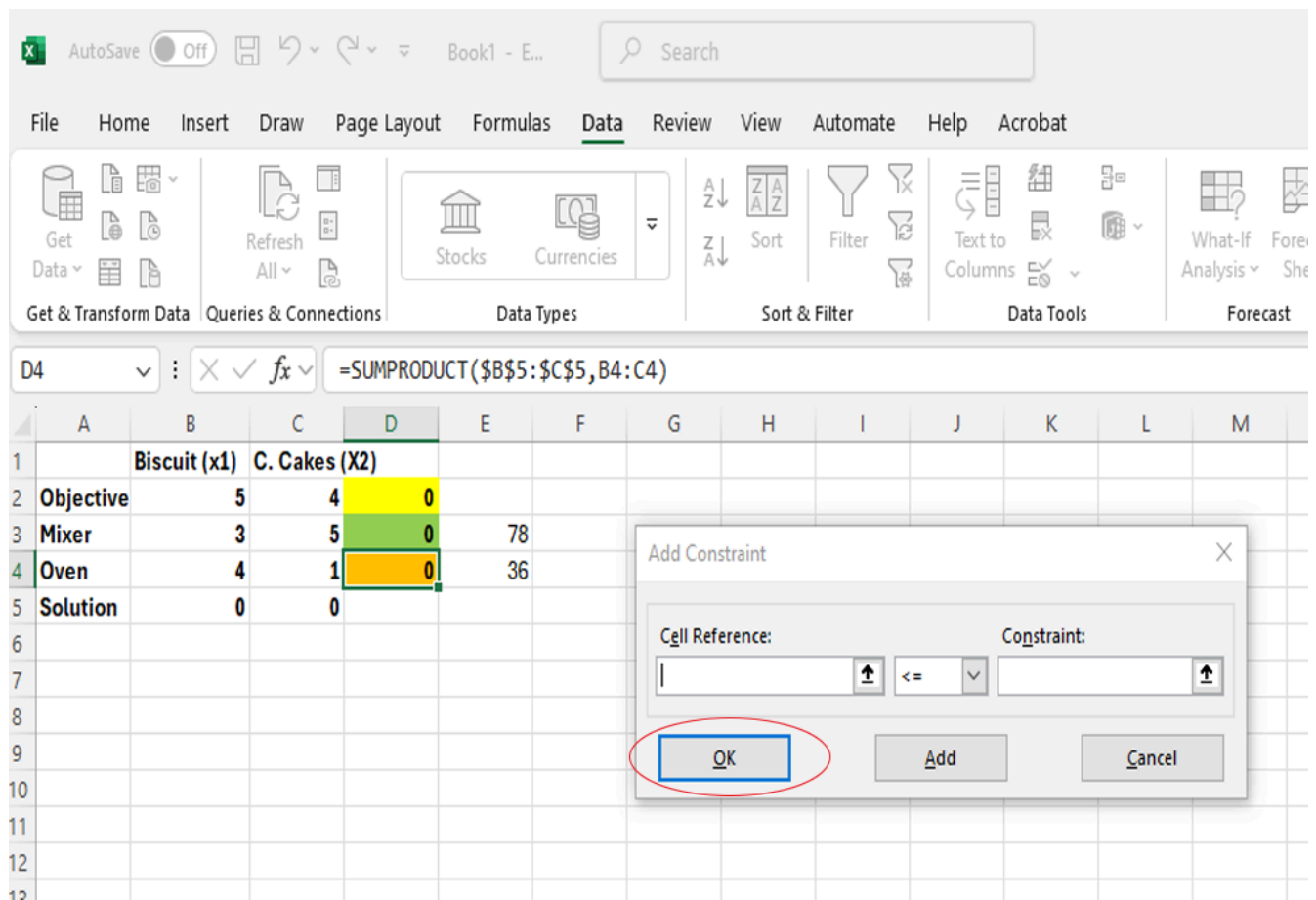


Image Description

Image 1: An Excel spreadsheet is shown with the “Solver Parameters” dialogue box open in the foreground. A red arrow points from the “Set Objective” field in the dialogue box to cell D2 in the spreadsheet, which is highlighted in green. A callout reads: “Step 1: Enter this cell.” The Solver dialogue box is used for setting up an optimization model. The spreadsheet in the background includes a linear programming problem with rows for Objective, Mixer, Oven, and Solution, and columns for two products: Biscuits (x1) and Cakes (x2). Calculated values in column D are highlighted in yellow, and resource limits appear in column E (78 for Mixer and 36 for Oven).

Image 2: An Excel spreadsheet with the “Solver Parameters” dialogue box open in the foreground. A callout labelled “Step 2: Max? or Min?” points to the “Set Objective” section of the dialogue box, where options to select either “Max” (maximize) or “Min” (minimize) are shown, with “Max” currently selected.

Image 3: An Excel spreadsheet is open with the “Solver Parameters” dialogue box displayed in the foreground. A red arrow points from the “Subject to the Constraints” section in the Solver box to the solution cells B5 and C5 in the spreadsheet, which contain zeros. A callout labelled “Step 3: Select the solution range and enter” is shown beside the constraint entry area.

Image 4: An Excel spreadsheet with the “Solver Parameters” dialogue box open in the foreground. A callout labelled “Step 4: Add the constraint by clicking on the Add Button” points to the “Add” button on the

the right side of the dialogue box, which is circled in red. The dialogue box includes options to set the objective, select Max or Min, and define changing variable cells and constraints.

Image 5: An Excel spreadsheet with the “Add Constraint” dialogue box open in the foreground. A red arrow points from the “Cell Reference” field in the dialogue box to cells D3 and D4 in the spreadsheet, which contain the values 0 and are highlighted in green and yellow. A callout labelled “Step 5: Select the left constraint range and enter” explains this action.

Image 6: An Excel spreadsheet is open with the “Add Constraint” dialogue box in the foreground. A red arrow points from the “Constraint” field in the dialogue box to cells G3 and G4 in the spreadsheet, which contain the values 78 and 36, representing resource limits for Mixer and Oven, respectively. A callout labelled “Step 6: Select the right constraint range and enter” explains this step.

Image 7: An Excel spreadsheet with the “Add Constraint” dialogue box open in the foreground. A callout labelled “Step 7: Click OK” points to the OK button, which is circled in red. The dialogue box contains filled-in fields for “Cell Reference” and “Constraint,” referring to the left (D3:D4) and right (E3:E4) constraint ranges in the spreadsheet.

Once the required parameters have been entered, the Solver Parameters dialogue box will be fully populated and ready for review, as illustrated below:

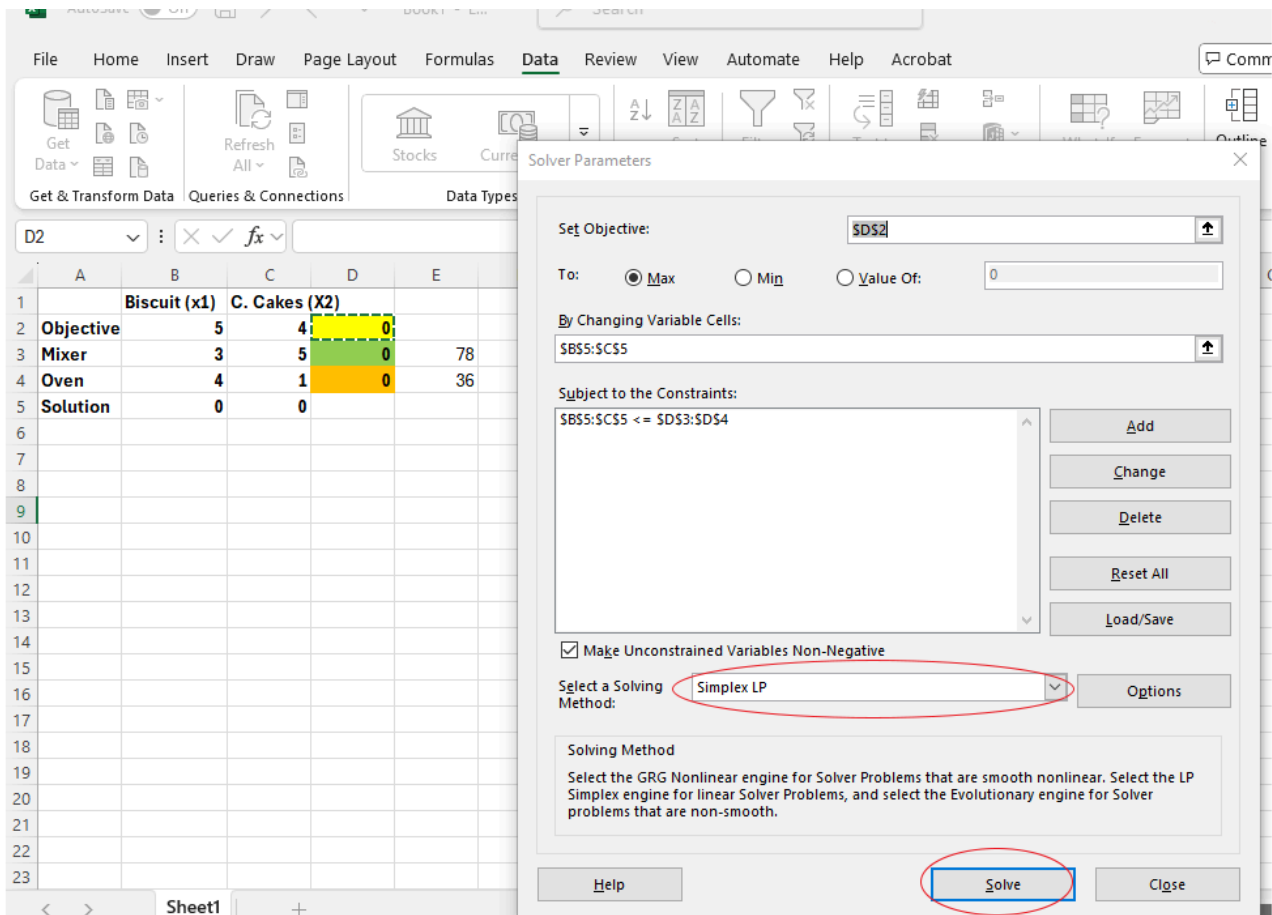


Figure 12.4.8 Excel Screenshot. © Microsoft.

12.4.8 Image Description

An Excel spreadsheet is shown alongside the “Solver Parameters” dialogue box. The objective cell is set to D2, aiming to maximize the objective. The “By Changing Variable Cells” field is set to \$B\$5:\$C\$5, representing the decision variables for Biscuits (x_1) and Cakes (x_2). A constraint is defined: \$B\$5:\$C\$5 * coefficients $\leq$ \$D\$3:\$D\$4 (resource totals for Mixer and Oven). The “Simplex LP” solving method is selected and circled, as is the “Solve” button at the bottom of the dialogue box. In the spreadsheet, the totals in column D are highlighted (green for D2 and yellow for D3 and D4). Resource constraints are shown in column F: 78 for Mixer and 36 for Oven.

Final Steps in Using Excel Solver

To complete the optimization process, follow these final steps:

1. *Select the Solving Method:*

In the Solver Parameters dialogue box, choose Simplex LP from the Select a Solving Method dropdown menu. This method is appropriate for linear programming problems.

2. *Click Solve:*

Once all parameters are correctly set, click the *Solve* button. Solver will process the model and return the optimal solution.

3. *Review and Accept the Solution:*

After Solver finds a solution, a dialogue box will appear displaying the results. Click *OK* to accept the solution and close the dialogue box. The optimal values will now be reflected directly in the Excel worksheet.

Interpreting the Solution

- *Decision Variables (Solution Row):*

Solver indicates that to maximize the objective function, the optimal solution is:

- x_1 (Biscuits) = 6 units
- x_2 (Cupcakes) = 12 units

- **Objective Function:**

The maximum profit (objective value) is \$78.

- **Constraints:**

- The *Mixer* constraint is fully utilized: 78 out of 78 available minutes are used.
- The *Oven* constraint is also fully utilized: 36 out of 36 available minutes are used.

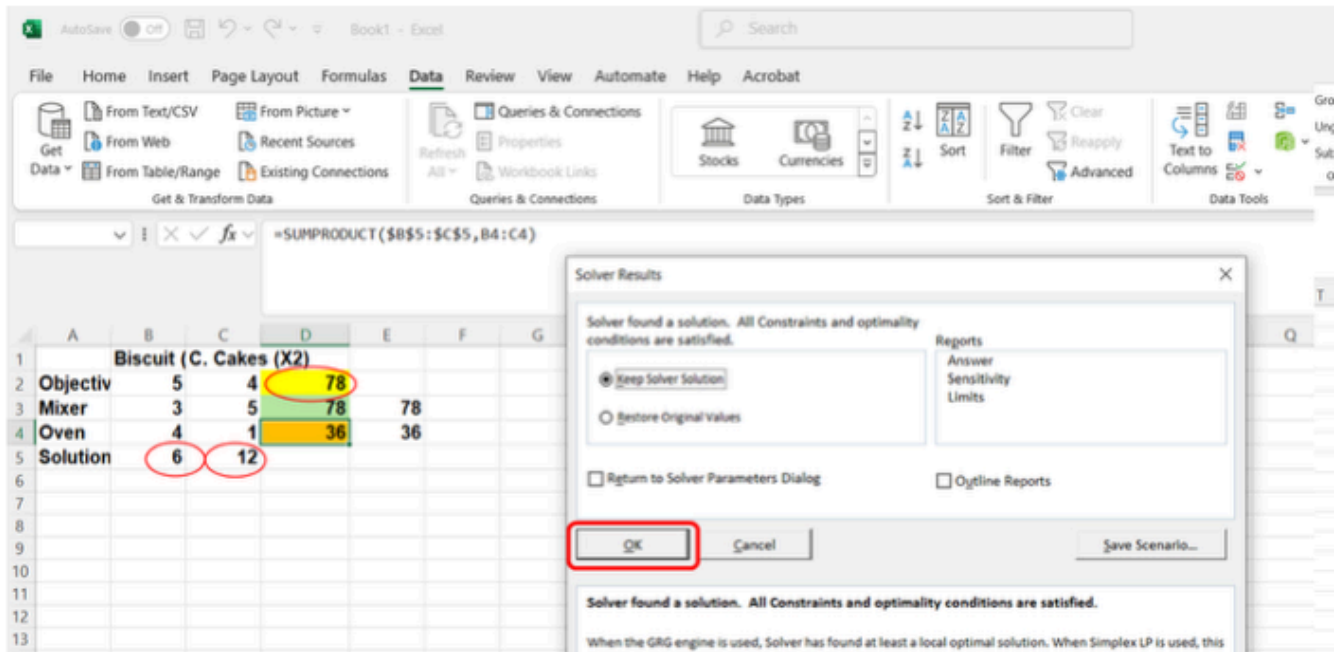


Figure 12.4.9 Excel Screenshot. © Microsoft

12.4.9 Image Description

This solution aligns with the results obtained using both the manual Simplex Method (as demonstrated in the accompanying video) and the graphical method discussed earlier.

12.5 SOLVING A TRANSPORTATION PROBLEM USING THE SIMPLEX METHOD IN EXCEL SOLVER

In [Chapter 11](#), we solved a transportation problem using the Stepping Stone and MODI methods. We will now revisit the same problem and solve it using the Simplex Method via Excel Solver.



Initial Transportation Cost

Using the initial basic feasible solution, the firm's transportation cost is calculated as follows:

Figure 12.5.1 Transportation Table

	M1	M2	M3	
DC1	150 6	50 9	16	0
DC2	11	150 10	50 7	0
DC3	16	12	200 10	0
	0	0	0	

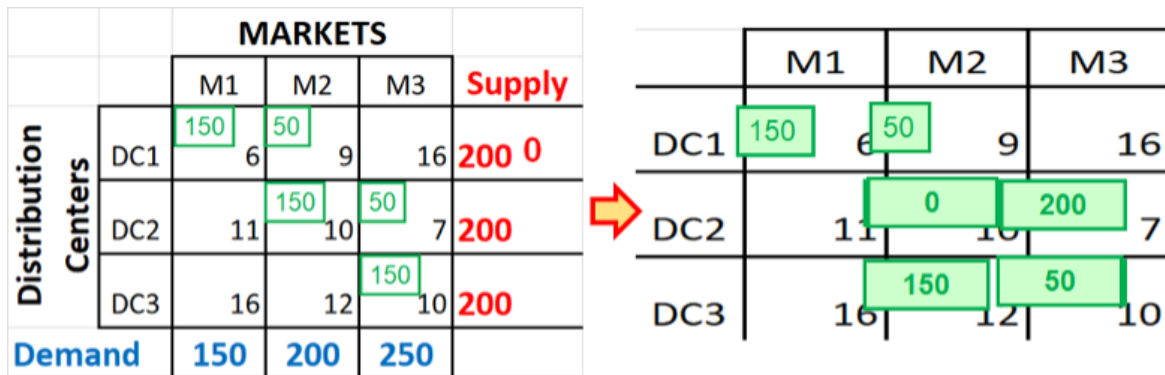
Total Cost:

$$150(6) + 50(9) + 150(10) + 50(7) + 200(10) = \$5,200$$

Stepping Stone Method

Using the **Stepping Stone Method**, the optimal solution was found to be:

$$150(6) + 50(9) + 0(10) + 200(7) + 150(12) + 50(10) = \$5,050$$



		MARKETS			Supply
		M1	M2	M3	
Distribution Centers	DC1	150	50	16	200 0
	DC2	11	150	50	200
	DC3	16	12	150	200
Demand		150	200	250	

	M1	M2	M3
DC1	150	50	16
DC2	11	0	200
DC3	16	150	50

Figure 12.5.2 Transportation Tables

12.5.2 Image Description

Two side-by-side transportation tables for a supply and demand allocation problem.

Left table: Distribution centers (DC1, DC2, DC3) are listed on the left, markets (M1, M2, M3) along the top. Each cell shows a shipping cost, with green numbers indicating allocated units. Supply is listed in red on the right (200 for each DC, with DC1 showing 0 remaining), and demand in blue along the bottom (150 for M1, 200 for M2, 250 for M3). Allocations: DC1 sends 150 to M1 and 50 to M2; DC2 sends 150 to M2 and 50 to M3; DC3 sends 150 to M1 and 50 to M3.

Right table: The same allocations are redrawn with green boxes around the numbers, visually emphasizing how shipments from DCs are distributed to meet the demands of markets.

Linear Programming Method

We will now formulate this problem as a linear programming problem (LPP) and solve it using the Excel Solver.

Objective: Minimize total transportation cost:

Figure 12.5.3 Transportation Table

		MARKETS			
		M1	M2	M3	Supply
Distribution Centers	DC1	X_{11} 6	X_{12} 9	X_{13} 16	200
	DC2	X_{21} 11	X_{22} 10	X_{23} 7	200
	DC3	X_{31} 16	X_{32} 12	X_{33} 10	200
Demand		150	200	250	

Minimize Z

$$Z : \min TC = X_{11}(6) + X_{12}(9) + X_{13}(16) + X_{21}(11) + X_{22}(10) + X_{23}(7) + X_{31}(16) + X_{32}(12) + X_{33}(10)$$

Subject to supply constraints:

- $X_{11} + X_{12} + X_{13} \leq 200$
- $X_{21} + X_{22} + X_{23} \leq 200$
- $X_{31} + X_{32} + X_{33} \leq 200$

And demand constraints:

- $X_{11} + X_{21} + X_{31} \leq 150$
- $X_{12} + X_{22} + X_{32} \leq 200$

- $X_{13} + X_{23} + X_{33} \leq 250$

All decision variables $X_{ij} \geq 0$

Implementing in Excel

1. Set up the cost matrix and decision variables in Excel.
2. Use SUMPRODUCT formulas to compute the total cost and the left-hand sides of the constraints.
3. Verify that all formulas are correctly implemented.
4. Open Solver and configure:
 - Objective: Minimize the total cost of the cell.
 - Variable Cells: All X_{ij} decision variables.
 - Constraints: Supply and demand constraints as listed above.
 - Solving Method: Select Simplex LP.

Figure 12.5.4

	X11	X12	X13	X21	X22	X23	X31	X32	X33	Left	Right
OBJE	6	9	16	11	10	7	16	12	10		
D1	1	11									200
D2				1	1	1					200
D3							1	1	1		200
M1	1			1			1				150
M2		1			1			1			200
M3			1			1			1		250
SOLUTION	0	0	0	0	0	0	0	0	0		

After all SUMPRODUCT formulas have been correctly implemented and verified, the model is now fully prepared for optimization. The Solver-ready layout of the transportation problem is shown below:

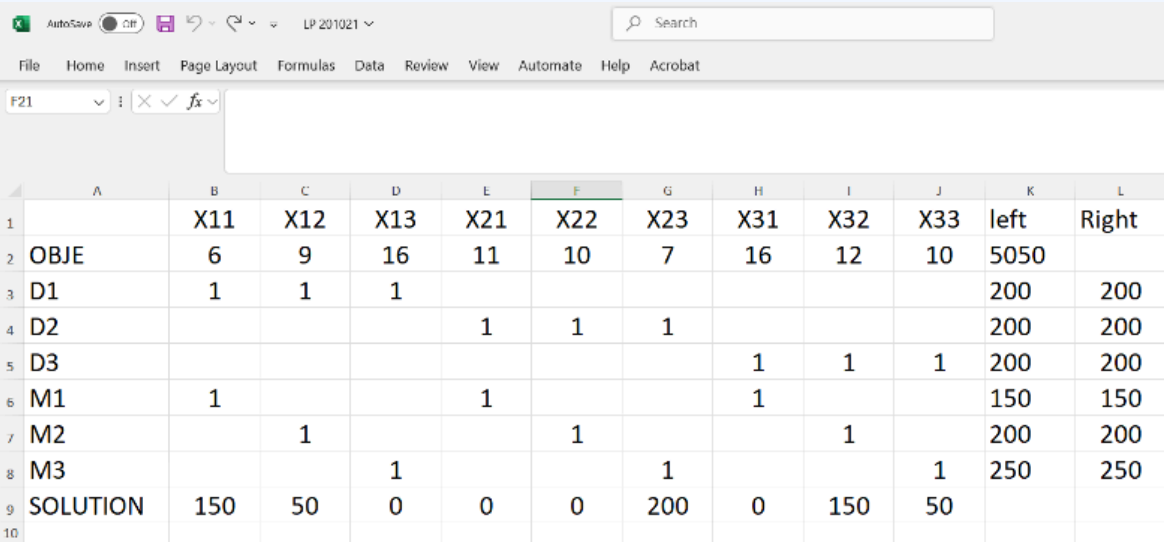
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1		X11	X12	X13	X21	X22	X23	X31	X32	X33	left	Right			
2	OBJE	6	9	16	11	10	7	16	12	10	0				
3	D1	1	1	1							0	200			
4	D2				1	1	1				=SUMPRODUCT(\$B\$9:\$J\$9,B4:J4)				
5	D3							1	1	1	0	200			
6	M1	1			1			1			0	150			
7	M2		1			1			1		0	200			
8	M3			1			1			1	0	250			
9	SOLUTION	0	0	0	0	0	0	0	0	0					
10															

Figure 12.5.5 Excel Spreadsheet linear programming solution.Excel Screenshot. © Microsoft.

12.5.5 Image Description

An Excel spreadsheet showing a linear programming or optimization setup with decision variables, constraints, and an objective function. The columns labelled X11 through X33 represent variables, while rows D1 to D3 and M1 to M3 list constraints. Row 2 (D1) has ones under X11, X12, and X13. Row 3 (D2) has ones under X21, X22, and X23. Row 4 (D3) has ones under X31, X32, and X33. Additional rows M1 to M3 contain other combinations of ones under different variables. The “OBJE” row at the top lists objective coefficients such as 6, 9, 16, 11, 10, etc. Columns K (“left”) and L (“Right”) contain constraint results, with right-hand side values 200, 150, 200, and 250. Row 10 (“SOLUTION”) currently has zeros under all variables. A formula bar shows =SUMPRODUCT(\$B\$9:\$J\$9,B4:J4)

The optimized solution, as computed by Excel Solver, is presented below:

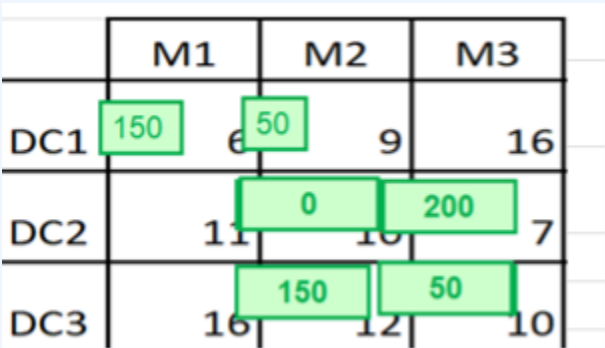


	A	B	C	D	E	F	G	H	I	J	K	L
1		X11	X12	X13	X21	X22	X23	X31	X32	X33	left	Right
2	OBJE	6	9	16	11	10	7	16	12	10	5050	
3	D1	1	1	1							200	200
4	D2				1	1	1				200	200
5	D3							1	1	1	200	200
6	M1	1			1			1			150	150
7	M2		1			1			1		200	200
8	M3			1			1			1	250	250
9	SOLUTION	150	50	0	0	0	200	0	150	50		
10												

Figure 12.5.6 Excel Spreadsheet linear programming solution.Excel Screenshot. © Microsoft.

12.5.6 Image Description

An Excel spreadsheet illustrating a linear programming solution, featuring variables X11–X33, objective values, demand and supply constraints, and solution values. The final solution assigns nonzero values to X11, X12, X23, X32, and X33, achieving an objective total of 5050.



	M1	M2	M3
DC1	150	50	16
DC2	11	0	7
DC3	16	150	10

Figure 12.5.7 Transportation Table

12.5.7 Image Description

A transportation table showing supply nodes (M1, M2, M3) across the top and demand centers (DC1, DC2, DC3) along the side. Each cell contains a cost value, with

green boxes displaying allocated shipment quantities. Allocations are: 150 from M1 to DC1, 50 from M2 to DC1, 200 from M2 to DC2, 150 from M1 to DC3, and 50 from M2 to DC3. Other routes have no allocation.

Solver Output

After solving, Excel Solver returns the following optimal allocation:

$$150(6) + 50(9) + 0(10) + 200(7) + 150(12) + 50(10) = 5,050$$

This matches the optimal solution previously obtained using the Stepping Stone method, confirming the validity of the Simplex-based approach in Excel.

12.6 CHAPTER SUMMARY & REVIEW



Summary

This chapter explores linear programming (LP) as a mathematical optimization tool for maximizing profit or minimizing cost under resource constraints. It explains the core components of a Linear Programming Problem (LPP)—the objective function, decision variables, constraints, and non-negativity conditions—and introduces the standard form for representing problems. Methods for solving LPPs include the graphical method (for two-variable problems) and the Simplex method (for larger problems), both of which systematically identify optimal solutions within the feasible region. A practical bakery example demonstrates how LP can guide production decisions to maximize profit, while Excel Solver is introduced as a user-friendly software application for solving LP models efficiently.

The chapter also connects LP to transportation models, showing how problems of distributing goods from multiple supply sources to multiple demand destinations can be optimized using the Simplex method in Excel Solver. It compares approaches to finding initial solutions, such as the North-West Corner, Least Cost, and Vogel's Approximation Methods, and covers optimization tools like the Stepping Stone and MODI methods. Finally, it highlights real-world applications of LP in product mix decisions, diet planning, and manufacturing resource allocation, emphasizing its role in improving efficiency, reducing costs, and supporting data-driven business decisions.

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Exercises

Exercise 1: Define a transportation model and its key components.

Answer:

A transportation model is a type of linear programming formulation used to minimize the cost of distributing goods from multiple supply sources to various demand destinations, subject to supply and demand constraints.

Key Components:

- Supply Points (e.g., factories or warehouses) with fixed capacities.
- Demand Points (e.g., markets or retailers) with fixed requirements.
- Transportation Costs per unit between each supply-demand pair.
- Decision Variables representing the quantity shipped along each route.

Exercise 2: Convert an unbalanced transportation problem into a balanced one.

Problem:

- Supply: 200 units (Warehouse A: 100, Warehouse B: 100)
- Demand: 180 units (Market X: 80, Y: 60, Z: 40)

Solution:

Since the total supply (200) exceeds the total demand (180), the problem is unbalanced. To balance it, introduce a dummy demand point with a requirement of 20 units and zero transportation cost from all supply points.

Exercise 3: Solve using the North-West Corner Method.

Problem Data:

- Supply: A (100), B (100)
- Demand: X (80), Y (60), Z (40)
- Costs:
 - A → X/Y/Z: 4 / 6 / 8
 - B → X/Y/Z: 5 / 3 / 7

Solution:

- A → X: 80 units (A: 20 remaining)
- A → Y: 20 units (Y: 40 remaining)
- B → Y: 40 units (B: 60 remaining)
- B → Z: 40 units (B: 20 remaining, unused)

Total Cost:

$$(80 \times 4) + (20 \times 6) + (40 \times 3) + (40 \times 7) = \$840$$

Exercise 4: Solve the same problem using the Least Cost Method.

- B → Y: 60 units (cost = \$3; B: 40 remaining)
- A → X: 80 units (A: 20 remaining)
- B → Z: 40 units (B: 0 remaining)
- A → Z: 20 units (A: 0 remaining)

Total Cost:

$$(60 \times 3) + (80 \times 4) + (40 \times 7) + (20 \times 8) = \$820$$

Exercise 5: Explain Vogel's Approximation Method (VAM).

Answer:

VAM calculates a penalty for each row and column by finding the difference between the two lowest costs. The highest penalty indicates the greatest opportunity cost. Allocation is made to the lowest-cost cell in that row or column, and the process repeats until all supply and demand are satisfied.

Exercise 6: Test for degeneracy in a 3×3 transportation problem with 4 allocations.

Answer:

Degeneracy occurs when the number of allocations is less than $m+n-1$, where m is the number of rows and n is the number of columns.

Here, $4 < (3+3-1) = 5$, so the solution is degenerate.

To resolve this, introduce a zero-quantity allocation in an unused cell to maintain feasibility.

Exercise 7: Optimize a solution using the Stepping Stone Method.

Given:

Initial cost = \$840 (from Question 3)

Optimization Steps:

- Evaluate unused route $A \rightarrow Z$
- Closed loop: $A-Z \rightarrow B-Z \rightarrow B-Y \rightarrow A-Y \rightarrow A-Z$
- Net cost change: $+8 -7 +3 -6 = -2$
- Reallocate 20 units along the loop

New Total Cost:

$$\$840 - (20 \times 2) = \$800$$

Exercise 8: When would you use the MODI method over the Stepping Stone method?

Answer:

The MODI (Modified Distribution) method is preferred for larger transportation problems because it is computationally more efficient. It uses dual variables to calculate improvement indices directly, avoiding the need to trace closed loops for each unused cell.

Exercise 9: Case Study: Mega Farms Distribution

Problem Data:

- **Warehouses:** W1 (50 tons), W2 (70 tons)
- **Markets:** M1 (40), M2 (30), M3 (50)
- **Costs:**
 - $W1 \rightarrow M1/M2/M3: 2 / 3 / 4$
 - $W2 \rightarrow M1/M2/M3: 5 / 1 / 3$

Solution Using VAM:

- Initial penalties: $W1 = 1, W2 = 2; M2 = 2$ (highest)
- Allocate $W2 \rightarrow M2$: 30 units (W2: 40 remaining)
- Allocate $W1 \rightarrow M1$: 40 units (W1: 10 remaining)
- Allocate $W1 \rightarrow M3$: 10 units (M3: 40 remaining)

- Allocate W2 → M3: 40 units

Total Cost:

$$(30 \times 1) + (40 \times 2) + (10 \times 4) + (40 \times 3) = \$270$$

Exercise 10: Why Are Transportation Models Critical in Supply Chain Management?

Transportation models play a vital role in supply chain management by enabling firms to:

- Minimize logistics and distribution costs, which directly improve profit margins.
- Optimize the use of available resources, such as transportation capacity and warehouse inventory.
- Ensure timely and efficient delivery of goods to meet customer demand.
- Enhance overall competitiveness by supporting data-driven decision-making in logistics planning.

These models provide a structured approach to solving complex distribution problems, making them indispensable tools in modern supply chain operations.

12.7 CASE STUDIES



Case Study 1: Product Mix Optimization

A company produces two products, A and B.

- Product A requires 2 hours of labour and 3 units of raw material per unit.
- Product B requires 3 hours of labour and 2 units of raw material per unit.
- Available resources: 100 labour hours and 90 units of raw material.
- Profit: \$40 per unit of A, \$30 per unit of B.

Formulate the LP model

Objective: Maximize profit:

$$Z = 40A + 30B$$

Subject to:

- Labor: $2A + 3B \leq 100$
- Raw material: $3A + 2B \leq 90$
- Non-negativity: $A, B \geq 0$



Case Study 2: Graphical Solution of an LP Problem

Maximize:

$$Z = 3x + 2y$$

Subject to:

- $X + y \leq 4$
- $X \leq 3$
- $Y \leq 2$
- $x, y \geq 0$

Solution:

Plot the feasible region defined by the constraints and identify the corner points. Evaluate the objective function at each corner to find the maximum value of Z .

The plot below shows:

- The constraint lines as solid curves.
- The feasible region is shaded in grey.
- An example objective function line $3x + 2y = 12$ is shown as a dashed line, which helps visualize the direction of optimization.

To find the optimal solution, you would slide the objective line parallel to itself toward the farthest point within the feasible region. The optimal value occurs at one of the corner points of the feasible region.

Corner points of the feasible region and their corresponding values for the objective function $Z = 3x + 2y$:

Corner Point	Objective Value $Z = 3x + 2y$
(0,0)	0
(3,0)	9
(0,2)	4

Corner Point	Objective Value $Z = 3x + 2y$
(3,1)	11 <- Optimal Solution
(2,2)	10

Optimal Solution:

- Point: (3,1)
- Maximum Value of Z : 11

This means the objective function reaches its maximum value of **11** at the point $x=3$, $y=1$, within the feasible region.

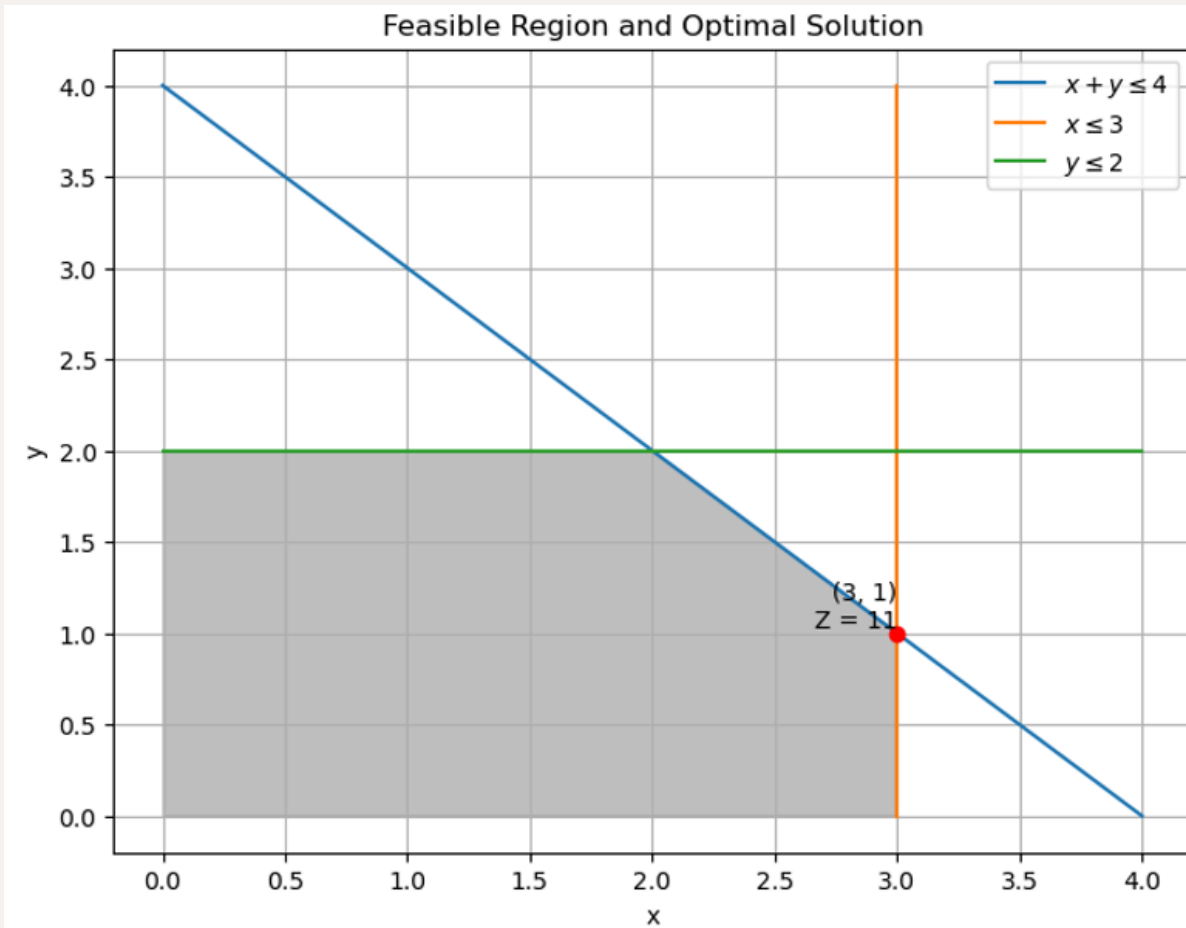


Image Description

A graph titled “Feasible Region and Optimal Solution” shows the feasible region for a linear programming problem. The x-axis ranges from 0 to 4, and the y-axis ranges from 0 to 4. Three constraint lines are drawn:

Blue line:

$x + y$

$\leq$

4

$x + y \leq 4$, sloping downward from (0, 4) to (4, 0).

Orange vertical line:


 $\leq$

3

 $x \leq 3.$

Green horizontal line:


 $\leq$

2

 $y \leq 2.$

The shaded gray region represents the feasible solution space, bounded below by the x-axis and the y-axis. The optimal solution is marked with a red dot at the point (3, 1), labelled “(3, 1), Z = 11.” This point lies on both the blue line and the orange line.



Case Study 3: Diet Optimization Problem

A nutritionist must design a diet that provides at least:

- 300 units of vitamin A
- 400 units of vitamin C

Two food options:

- *Food X:* 50 units of A, 20 units of C per ounce, costs \$3
- *Food Y:* 20 units of A, 50 units of C per ounce, costs \$4

Formulate the LP model.

Objective: Minimize cost:

$$Z = 3X + 4Y$$

Subject to:

- Vitamin A: $50X + 20Y \geq 300$
- Vitamin C: $20X + 50Y \geq 400$
- Non-negativity: $X, Y \geq 0$



Case Study 4: Manufacturing Resource Allocation

A fabrication department produces four parts: A, B, C, and D.

- Variable costs: A = \$3, B = \$2, C = \$5, D = \$1
- Machines: Laser Cutter (max 10 hrs), Edge Filer (8 hrs), Spot Welder (5 hrs)

Machine time requirements (in hours):

Part	Laser Cut	Edge File	Spot Weld
A	2	1	1
B	1	2	1
C	3	1	1
D	0	0	0

Objective: Minimize total cost:

$$Z = 3A + 2B + 5C + 1D$$

Subject to:

- Laser Cut: $2A + B + 3C \leq 10$
- Edge File: $A + 2B + C \leq 8$
- Spot Weld: $A + B + C \leq 5$
- Non-negativity: $A, B, C, D \geq 0$

Question:

How many units of each part should be fabricated to minimize total cost?

12.8 KEY TERMS



Key Terms

- **Constraints:** Limitations or requirements (expressed as inequalities or equations) that the decision variables must satisfy, often related to resources like time or budget.
- **Corner Points (Vertices):** The intersection points of constraint lines in the feasible region. These are evaluated to find the optimal value in the graphical method.
- **Decision Variables:** Unknown quantities in an LPP whose values are to be determined (e.g., number of units to produce).
- **Excel Solver:** An optimization tool in Microsoft Excel that can solve LPPs using built-in algorithms like the Simplex LP method.
- **Graphical Method:** A visual technique for solving LPPs with two variables by plotting constraints on a graph and identifying the feasible region and optimal point.
- **Linear Programming (LP):** A mathematical technique used to optimize a specific objective (e.g., maximize profit or minimize cost) subject to a set of linear constraints.
- **Linear Programming Problem (LPP):** A mathematical model representing a real-world situation where the objective and constraints are linear. It includes an objective function, decision variables, and constraints.
- **Non-negativity Constraints:** A condition in LP that ensures all decision variables are equal to or greater than zero, reflecting real-world scenarios where negative values aren't feasible.

- **Objective Function:** The formula that defines what needs to be optimized in an LPP—either maximized (e.g., profit) or minimized (e.g., cost).
- **Simplex Method:** An algebraic method used to solve LPPs with more than two variables. It systematically moves from one vertex to another to improve the objective value until optimality is reached.
- **Slack Variables:** Variables added to constraints to convert inequalities into equalities in the Simplex Method, representing unused resources.
- **Standard Form (of an LPP):** A canonical form where the objective is either maximized or minimized, all constraints are expressed as linear inequalities ($\leq$), and variables are non-negative.
- **Stepping Stone Method:** An optimization technique used in transportation models that tests the potential of unused routes via closed loops to reduce costs.
- **SUMPRODUCT Function:** An Excel function used to compute dot products, useful for defining objective functions and constraint expressions in LP models.

CHAPTER 13: INVENTORY MANAGEMENT

Chapter Overview

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[13.1 Introduction to Inventory Management](#)

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13.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Explain the fundamental role of inventory management in balancing customer service levels and inventory costs.
- Classify and describe the different types of inventory managed by organizations.
- Analyze the various reasons for maintaining inventory and their impact on inventory management strategies.
- Identify and explain the components of inventory holding costs and their influence on inventory management decisions.
- Calculate the optimal order quantity using the EOQ formula and assess its impact on total relevant costs.
- Apply the EPQ model to determine the optimal production run size and its implications for inventory management.
- Calculate safety stock and reorder points based on demand variability and service level requirements.

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13.1 INTRODUCTION TO INVENTORY MANAGEMENT

Inventory management plays a crucial role in industrial operations by overseeing the material resources that generate future revenue for an organization. This responsibility falls under the purview of the Operations Manager. Consider a retail store selling various products like packaged foods, groceries, apparel, and electronics. Typically, not all merchandise is stored within the store premises. A portion of the stock is kept in a warehouse facility. The combined inventory, comprising goods in the store and warehouse at any given time, constitutes the total inventory.



“Warehouse” by Secom Bahia, CC BY 2.0

This chapter will explore inventory management models that deal with certain or known demands. These models aim to address two fundamental questions:

1. How many units to order
2. When to place the order for those units

The primary objective of inventory control or inventory management is to achieve satisfactory levels of customer service while keeping inventory costs at a reasonable level. Therefore, there is a trade-off between the amount of inventory held and the level of customer service provided.

13.2 TYPES OF INVENTORY

Organizations typically manage several types of inventory, including:



Figure 13.2.1 “Types of Inventory” by Koen Liddiard, [CC BY NC SA](#)

1. **Raw materials or purchased parts:** These are the basic components or materials required for production or assembly processes.
2. **Work in process (WIP) or work in progress:** These are semi-finished or partially completed items found in the middle of assembly lines and manufacturing facilities.
3. **Finished goods or merchandise:** These are the final products ready for sale and distribution to customers, commonly found in retail stores and warehouses.
4. **Spare parts, tools, and supplies:** These are additional inventory items required for maintenance, repair, and operational purposes within the organization.

Understanding and effectively managing these different types of inventory is crucial for organizations to

ensure smooth operations, meet customer demand, and maintain optimal inventory levels. The inventory management models discussed in this chapter will provide insights and techniques to help organizations make informed decisions regarding order quantities and timing, ultimately leading to improved customer service and cost efficiency.

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13.3 REASONS FOR MAINTAINING INVENTORY

Organizations maintain inventory for various reasons, including:

- *In-Transit Inventory:* Inventory may be held simply because it is in transit and has not yet arrived at the facility. Since payment has been made for these goods, they are counted as part of the organization's inventory, referred to as in-transit inventory holding.
- *Preventing Stock-Outs:* One of the most common reasons for keeping inventory is to protect against stock-outs. When customers request to purchase a product, organizations aim to have sufficient stock available to meet the demand.
- *Leveraging Quantity Discounts:* Suppliers may offer quantity discounts for larger purchases. Although the organization may not immediately require the additional units, they may choose to purchase in bulk to take advantage of these discounts, resulting in excess inventory.
- *Smoothing Production Requirements:* Inventory can help organizations smooth out production requirements when demand fluctuates. During periods of low demand, they may produce more and stockpile inventory to avoid ramping up production excessively when demand increases again. This approach helps maintain a steadier production level, which is often more cost-effective.
- *Mitigating Operational Disruptions:* Maintaining inventory can help organizations cover for disruptions in specific production processes. In case of operational issues, having sufficient inventory on hand can prevent complete shutdowns or delays until the problem is resolved.
- *Cost Considerations:* In all these scenarios, organizations must carefully weigh the holding costs of inventory against other costs. For instance, if holding costs are high, they may prefer to risk occasional stock-outs rather than carrying excessive inventory. Alternatively, they may forgo supplier discounts if the total savings do not justify the additional inventory holding costs.
- *Inventory Management Models:* In inventory management, demand is classified as either known or steady versus uncertain. Several factors influence the choice of inventory model, including lead time and review time.
- *Lead Time:* Lead time refers to the duration between placing an order with a supplier and receiving the ordered goods. This factor plays a crucial role in determining the appropriate inventory model and ensuring timely replenishment.
- *Review Time:* Review time pertains to the frequency at which inventory levels are monitored. Two common approaches exist:

- *Continuous Review*: In this method, an information system continuously tracks inventory levels and triggers a reorder notification or automatically places an order when stock reaches a predetermined reorder point. This automated process eliminates manual intervention and ensures timely order placement with pre-established suppliers.
- *Periodic Review (Fixed Order Interval)*: Alternatively, inventory levels can be reviewed at fixed intervals. At the end of each interval, if the stock falls below a predetermined maximum level, an order is placed for the difference between the current stock and the maximum level. This approach allows for periodic adjustments based on actual demand patterns.
- *Additional Considerations*: Other factors, such as product perishability or obsolescence, may further complicate inventory models. For perishable items like food products, the product's lifespan must be carefully considered to avoid overstocking and subsequent waste or loss of inventory value due to expiration or obsolescence. Failing to account for these factors can result in significant financial losses.

While the above factors are fundamental to inventory management models, additional variables specific to an organization's operations or product characteristics may necessitate more intricate modelling approaches to optimize inventory levels and minimize costs.

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13.4 RELEVANT COSTS

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

Total Purchasing or Acquisition Cost

Total purchasing or acquisition costs refer to the total expenditure incurred by an organization in procuring an item over a specific period, such as a year, quarter, or month. The time unit used for measurement depends on the organization's operational requirements.

In certain inventory models, this cost component may remain constant. This scenario arises when the total demand for the item remains unchanged throughout the period, and the supplier does not offer any quantity discounts. In such cases, the total acquisition cost or purchasing cost is fixed, as it does not vary based on the order quantities placed.

Consequently, in these scenarios, the total acquisition cost is often excluded from the mathematical models used to determine optimal order quantities. Since this cost component is fixed and does not change based on the order size, it does not influence the optimization calculations.

However, it is important to note that if the total demand or supplier pricing varies or quantity discounts are available, the total acquisition cost may become a variable component that must be incorporated into the optimization models.

By carefully analyzing the demand patterns, supplier pricing strategies, and the availability of quantity discounts, organizations can determine whether the total purchasing or acquisition cost should be treated as a fixed or variable component in their inventory management models. This approach ensures accurate cost considerations and facilitates the determination of optimal order quantities, ultimately contributing to operational efficiency and cost minimization.

Inventory Holding Costs

Inventory holding costs aim to capture all the actual and opportunity costs incurred by an organization in maintaining its inventory. The main components of holding costs include: financing costs, storage and handling costs, inventory risk costs and insurance.

Financing Costs

Inventory represents a significant portion of a firm's assets and working capital. This holding cost component is often estimated as the cost of borrowing or the opportunity cost of deploying funds for alternative uses. The most accurate estimate is the weighted average cost of capital used in capital budgeting decisions. This cost component is directly proportional to the value of the firm's inventory.

Storage and Handling Costs

These costs are incurred due to the physical storage of inventory and are typically a function of the item's size rather than its value. Storage costs may include expenses related to the physical space required for inventory storage. However, these costs are irrelevant when calculating pipeline inventory (inventory in transit).

Inventory Risk Costs

This component accounts for the costs associated with deterioration, obsolescence, shrinkage, theft, or damage to inventory. The level of risk and associated costs depend on the nature of the item. For instance, fashion goods, perishable products, and high-technology items will likely have higher inventory risk costs due to their shorter shelf life or rapid obsolescence.

Insurance

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

By carefully considering and quantifying these components, organizations can accurately estimate their inventory holding costs and make informed decisions regarding inventory levels, storage

strategies, and risk mitigation measures. Managing inventory holding costs effectively can contribute to overall operational efficiency and profitability.

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 why companies tend to keep as few units as possible for those items when dealing with more expensive 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’ pick up later. They could not afford to keep several of those very expensive items in the store because otherwise, the cost of holding them would be very high.”

Calculating Inventory Holding Costs

In operations management, inventory holding costs are typically calculated as a percentage of the item’s value. This approach allows organizations to estimate the cost of holding a particular item in stock for a specific period.



Example Scenario

Consider an item valued at \$1,000, and the organization's inventory holding cost is 20% per annum.

Annual Holding Cost per Unit

If the organization holds one unit of this item for an entire year, the annual holding cost would be:

Annual Holding Cost per Unit = Item Value × Inventory Holding Cost Percentage

Annual Holding Cost per Unit = \$1,000 × 0.2 = \$200

Holding Cost for a Partial Year

If the same item is held in inventory for only a quarter of the year (3 months), the holding cost per unit would be:

Quarterly Holding Cost per Unit = $(\frac{1}{4}) \times$ Annual Holding Cost per Unit.

Quarterly Holding Cost per Unit = $(\frac{1}{4}) \times \$200 = \$50$

Total Annual Holding Cost for Multiple Units

If the organization holds 10 units of this item for an entire year, the total annual inventory holding cost would be:

Total Annual Holding Cost = Number of Units × Annual Holding Cost per Unit

Total Annual Holding Cost = 10 × \$200 = \$2,000

Organizations can accurately estimate the expenses associated with maintaining inventory levels by calculating inventory holding costs as a percentage of the item's value. This approach allows for effective inventory management, cost optimization, and informed decision-making regarding order quantities and inventory levels.

Ordering Costs

Ordering costs refer to the expenses incurred by an organization when placing an order for inventory replenishment. These costs comprise several components: administrative costs, transportation costs, receiving costs,

Administrative Costs

Placing an order involves administrative tasks such as preparing purchase orders, obtaining necessary approvals, and completing other formalities. The administrative cost component includes all fixed costs associated with these activities, regardless of the order size. Electronic ordering systems can help reduce the time and effort required, thereby minimizing this cost component.

Transportation Costs

A fixed transportation cost is often incurred when transporting ordered goods, regardless of the order size. This cost component accounts for the logistics expenses associated with the delivery of inventory.

Receiving Costs

Upon receiving an order, administrative work is required, such as preparing goods receipt notes, updating inventory records, and verifying the order against the respective purchase order. The receiving cost component accounts for the expenses associated with these receiving activities.

It is important to note that all fixed costs, which do not vary with the order quantity, should be included in the ordering costs. Conversely, costs that vary with the order size should be included in the cost of the item itself.

In a purchasing environment, a significant portion of the ordering cost is information-intensive. Implementing electronic ordering systems can substantially reduce these costs. In a production environment, the ordering cost is referred to as the setup cost, which is the fixed cost associated with preparing machinery or equipment for production, also called Economic Production Quantity (EPQ). Unlike purchasing environments, setup costs are less information-intensive and are primarily influenced by the time lost during

the setup activity. Consequently, in production environments, the focus is on reducing setup time to minimize these costs.

By carefully considering and quantifying these components, organizations can accurately estimate their ordering costs and make informed decisions regarding order quantities, inventory levels, and potential cost-saving measures, such as implementing electronic ordering systems or optimizing setup processes.

Stock-Out Costs

Stock-out costs refer to the economic consequences an organization faces when it runs out of stock for a particular item. There are two possible scenarios in this situation: either the customer is willing to wait for the item to be restocked (backorder), or the customer's order cannot be fulfilled from the current inventory (lost sale). Stock-out costs can be categorized into two types: lost sales costs, and backorder costs.

Lost Sales Costs

When a company cannot fulfill a customer's order due to a lack of finished goods inventory, it results in a lost sale. The associated cost is the opportunity cost of the potential profit from that transaction. Additionally, lost sales can negatively impact the company's goodwill and future sales prospects.

Backorder Costs

Backorder costs are incurred when a customer is willing to wait for their order to be fulfilled after the item is restocked. In such cases, the organization incurs additional administrative costs and potential additional transportation and handling costs if the material needs to be rushed through to meet the backorder. While some of these costs are tangible, backorder costs also include intangible costs related to the firm's goodwill and potential impact on future sales.

It is important to note that stock-out costs are often intangible and difficult to measure precisely. However, organizations must consider these costs when making inventory management decisions, as they can significantly impact customer satisfaction, profitability, and long-term business performance.

By implementing effective inventory management strategies and maintaining appropriate stock levels, organizations can minimize the occurrence of stock-outs and the associated costs, thereby enhancing customer satisfaction, operational efficiency, and overall profitability.

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13.5 INVENTORY MODELS FOR CERTAIN DEMAND: ECONOMIC ORDER QUANTITY (EOQ) MODEL

The Economic Order Quantity (EOQ) model is a fundamental inventory management model used when the following assumptions hold:

Assumptions

- The item is ordered from an external supplier (no internal production)
- Demand is fixed or steady over time (known with certainty)
- Lead time (the duration between order placement and receipt) is constant
- A fixed order quantity is placed each time
- The ordering cost is fixed per order, regardless of order size

Inventory Control Cycles

Each order placement initiates an inventory control cycle or order cycle. Upon receiving an order, the inventory level increases, and as demand is satisfied, the inventory level decreases over time. When the inventory level reaches a predetermined reorder point, a new order is placed, and the cycle repeats.

The inventory level fluctuates, as shown in the following diagram:

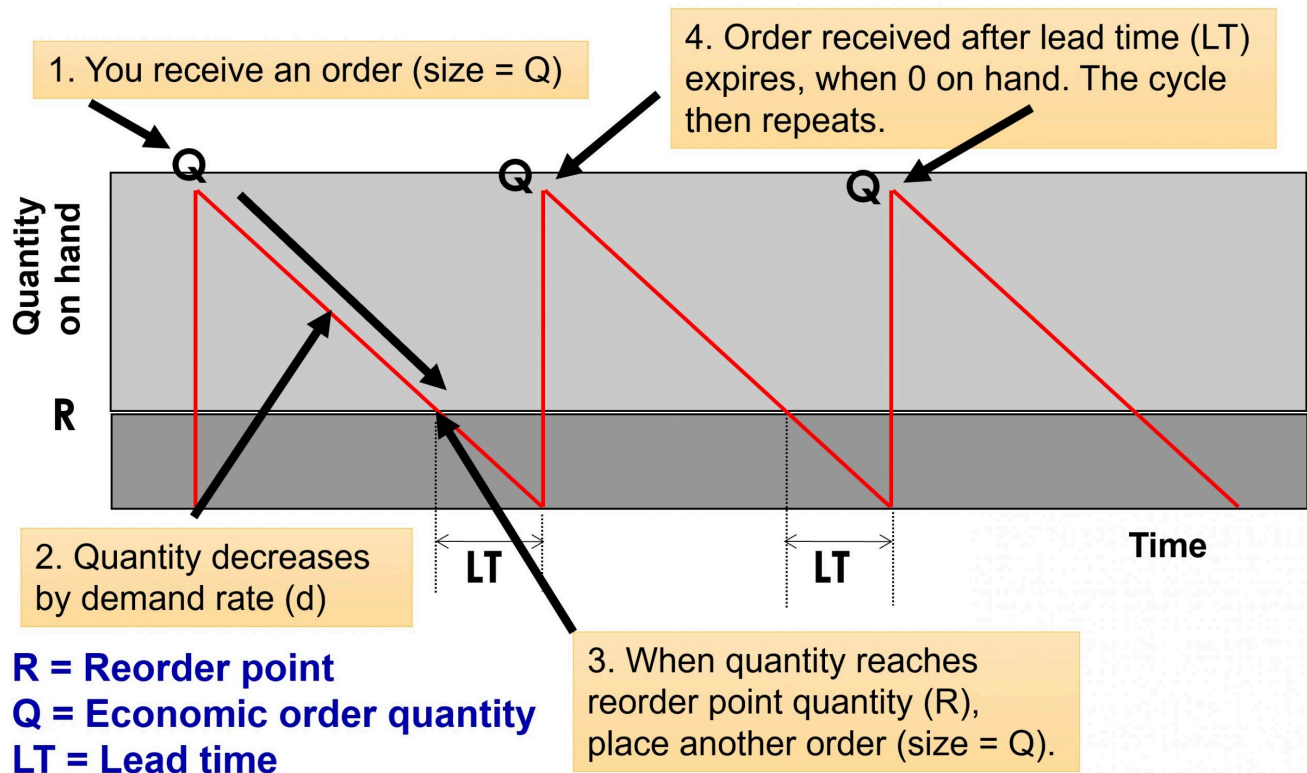


Figure 8.5.1: A diagram showing how the inventory level change over time

At point 1, an order of quantity Q is received, increasing the inventory level from zero to Q units. As time progresses, the inventory level decreases due to demand. When the inventory level reaches the reorder point R , a new order is placed to ensure that the order is received just as the inventory level reaches zero, preventing stock-outs.

Objective and Cost Components

The objective of the EOQ model is to determine the optimal order quantity (Q^*) that minimizes the total relevant costs, which include:

1. Total Ordering Costs
2. Total Inventory Holding (Carrying) Costs

Other costs, such as total acquisition (purchasing) costs and shortage costs, are excluded from the model due to the assumptions of fixed demand and no stock-outs.

Notation and Calculations

Let:

D = demand (units/year)

Q = order quantity

S = order cost (\$/order)

H = carrying cost (\$/item/year)

I_{avg} = Average inventory

N = number of orders per year

TC = Total Cost

Total Cost = Ordering cost + Carrying cost

$$TC = (S \times N) + (H \times I_{avg})$$

$$TC(Q) = (S \times D \div Q) + (H \times Q \div 2)$$

The number of orders per year (N) can be calculated as $N = D \div Q$.

The average inventory level is $Q \div 2$, assuming a constant demand rate.

The total relevant cost function, $TC(Q)$, is given by:

$$TC(Q) = (D \div Q) \times S + (Q \div 2) \times H$$

By setting the derivative of $TC(Q)$ with respect to Q equal to zero and solving for Q , the optimal order quantity Q^* is obtained:

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

This optimal order quantity minimizes the total relevant costs for the given demand, ordering cost, and holding cost parameters.

The EOQ model provides a straightforward approach to determining the optimal order quantity when demand is certain, and other assumptions are met, enabling organizations to optimize their inventory management strategies and minimize associated costs.

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

Video: "[Inventory Management: Economic Order Quantity \(EOQ\) Model Video 1](#)" by [Excel@Analytics – Dr. Canbolat](#) [15:25] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*



Examples

Example 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

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

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

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

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

Example 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:

- Optimal order quantity per order
- Minimum total annual inventory costs
- The optimal number of orders per year
- The time between orders (in working days)

Solution

$$D = 1500$$

$$S = \$625$$

$$H = \$130$$

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

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

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

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

Example 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:

- The optimal number of yards of material Modern Furniture should order
- The minimum total inventory cost
- The optimal number of orders per year, and
- The optimal time between orders

Solution

$$D = 45,000$$

$$S = \$1500$$

$$H = \$0.70$$

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

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

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

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

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13.6 INVENTORY MODELS FOR CERTAIN DEMAND: ECONOMIC PRODUCTION QUANTITY (EPQ)

The Economic Production Quantity (EPQ) model is applicable when an organization has its own internal production capabilities rather than ordering from an external supplier. Unlike the Economic Order Quantity (EOQ) model, where inventory is received in a single batch, the EPQ model accounts for a gradual replenishment of inventory through production.

Key Differences from EOQ

1. **Production Setup Cost:** In the EPQ model, there is a production setup cost associated with preparing the machines or production area before commencing each production run or cycle.
2. **Gradual Inventory Replenishment:** Instead of receiving the entire order quantity (Q) at once, as in the EOQ model, the inventory level increases gradually during the production uptime or run time.

Inventory Level Behaviour

The inventory level fluctuates in a distinct pattern under the EPQ model, as illustrated in the following diagram



Figure 8.6.1: A chart showing how the inventory level changes over time

The red line in the diagram represents the fluctuating inventory level over time. During the uptime or run time ($T1$), production is ongoing at a rate of p units per day, while customer demand is occurring simultaneously at a rate of d units per day. Consequently, the inventory level increases at a rate of $(p - d)$ units per day, reflecting the net accumulation of inventory.

Production continues until the inventory level reaches a predetermined maximum level. At this point, production is halted, and the accumulated inventory is utilized solely to satisfy customer demand during the downtime period ($T2$). During the downtime, the inventory level gradually decreases as the piled-up stock is depleted to meet demand.

A fundamental assumption of the EPQ model is that the production rate (p) exceeds the demand rate (d). If this assumption is violated, and the demand rate surpasses the production rate, the organization will inevitably face stock-outs, as the production capacity would be insufficient to replenish the inventory at the required rate.

By adhering to the condition of $p > d$, the EPQ model ensures that the production process can consistently replenish inventory levels, enabling the organization to meet customer demand without experiencing stock-outs during the downtime period. This assumption is crucial for maintaining a stable inventory management system and ensuring uninterrupted operations.

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

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

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

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

$$T_2 = \text{Downtime} = T - T_1$$

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

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

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

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

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. The 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:

- The optimal run size
- The minimum total annual cost for carrying and setup
- Cycle time for the optimal run size
- The production run time (uptime)
- 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 = $H = \$1$

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

- The optimal run size

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

- The minimum total annual cost for carrying and setup

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

- 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

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

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13.7 INVENTORY MODELS FOR UNCERTAIN DEMAND

The previous models are valid on the assumption that the market demand is known and stays unchanged. However, sometimes, the market demand could change unexpectedly. This could lead to an inventory shortage, which would change the reorder point. To keep pace with the market, it would be prudent to consider the oscillation in demand during lead time and add in a safety stock. The demand oscillation is commonly measured in terms of the standard deviation (δ) from the average demand during the total time for an order as calculated below:

$$\delta_L = \delta_t \sqrt{L}$$

Knowing the demand variation, the safety stock should be considered to avoid stock out. However, the level of certainty for not facing stock out must also be considered. For example, if we choose to have 95% certainty that stock out and backorder does not happen (also known as Cycle Service Level), then we are reducing the risk of stock out to 5% (100%-95%). Assuming that the demand during lead time is normally distributed, the Z value (Z table) for the selected certainty level would be multiplied to the calculated δ_L to determine the Safety stock as shown below:

$$SS = Z\delta_L$$

The incorporation of safety stock, based on the cycle service level, would move the reordering point to:

$$ROP = d_L + SS$$



Example

A cell phone kiosk has an average demand of 20 phones per week with a variation of 4 phones. The lead time for this kiosk is always 1 week. The Kiosk wishes to maintain a 90% cycle service level. What would be the safety stock and reorder point for this kiosk?

Solution

$$\delta_L = \delta_t (\sqrt{L}) = 4 (\sqrt{1}) = 4$$

$$SS = Z\delta_L = 1.28 (4) = 5.12 \text{ or } 5$$

Note: Z value for 90% in Z table is 1.28

$$ROP = \delta_L + SS = 4 + 5 = 9$$

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13.8 CHAPTER SUMMARY & REVIEW



Summary

Inventory management is a critical function in industrial operations, focusing on the oversight of material resources to ensure future revenue. This chapter explores inventory management models that address the fundamental questions of how many units to order and when to place these orders, with the objective of balancing customer service levels and inventory costs. Various types of inventory are discussed, including raw materials, work in process, finished goods, and spare parts. The reasons for maintaining inventory range from preventing stock-outs and leveraging quantity discounts to smoothing production requirements and mitigating operational disruptions.

The chapter delves into relevant inventory costs, such as purchasing, holding, and ordering costs. Holding costs include financing, storage, handling, risk costs, and insurance, which can be significant for high-value items. Ordering costs encompass administrative, transportation, and receiving expenses. The Economic Order Quantity (EOQ) model is highlighted as a method to determine the optimal order quantity that minimizes total relevant costs by balancing ordering and holding costs; that is, an order quantity at which these two costs are equal. The chapter also covers the Economic Production Quantity (EPQ) model, which is applicable for internal production, and inventory models for uncertain demand, emphasizing the importance of safety stock and cycle service levels to prevent stock-outs.

Overall, this chapter provides comprehensive insights into inventory management strategies, including the calculation of relevant costs and the application of various inventory models. By understanding and implementing these models, organizations can

optimize their inventory levels, reduce costs, and improve customer service, ultimately enhancing operational efficiency and profitability.

OpenAI. (2024, June 18). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than three paragraphs. Reviewed by authors.*



Review Questions

1. Explain the role of inventory management in industrial operations. Why is it important for Operations Managers to oversee inventory?
2. Identify and describe the different types of inventory managed by organizations. Provide examples of each type in a specific industry.
3. Discuss the various reasons organizations maintain inventory. How do these reasons impact the overall inventory strategy?
4. What are the key components of inventory holding costs? How do these costs influence inventory management decisions?
5. Describe the EOQ model and its assumptions. How does this model help in determining the optimal order quantity?
6. Compare and contrast the EOQ and EPQ models. In what situations would an organization use the EPQ model instead of the EOQ model?
7. Explain the concept of stock-out costs. How do lost sales and backorder costs affect a company's inventory management policies?
8. How do inventory models for uncertain demand differ from those for certain demand? Discuss the role of safety stock in managing uncertain demand.
9. How are inventory holding costs typically calculated in operations management? Provide an example calculation to illustrate this process.
10. Define lead time and review time in the context of inventory management. How do these factors influence the choice of inventory model and order quantities?

OpenAI. (2024, June 18). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create ten discussion questions based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

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13.9 KEY TERMS



Key Terms

- **Backorder costs** are incurred when a customer is willing to wait for their order to be fulfilled after the item is restocked.
- **Finished goods or merchandise:** These are the final products ready for sale and distribution to customers, commonly found in retail stores and warehouses.
- **Inventory holding costs** aim to capture all the actual and opportunity costs incurred by an organization due to maintaining inventory.
- **Ordering costs** refer to the expenses incurred by an organization when placing an order for inventory replenishment.
- **Raw materials or purchased parts:** These are the basic components or materials required for production or assembly processes.
- **Spare parts, tools, and supplies:** These are additional inventory items required for maintenance, repair, and operational purposes within the organization.
- **Stock-out costs** refer to the economic consequences an organization faces when it runs out of stock for a particular item.
- **Total purchasing or acquisition costs** refer to the total expenditure incurred by an organization in procuring an item over a specific period, such as a year, quarter, or month.
- **Total Cost of Optimal Order size (TC(Q))** is the sum of ordering cost (S) and holding cost (H). At its minimal level, ordering cost and holding cost are equal.
- **Work in process (WIP) or work in progress:** These are semi-finished or partially completed items found in the middle of assembly lines and manufacturing facilities.

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CHAPTER 14: AGGREGATE PLANNING

Chapter Overview

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[14.3 Aggregate Planning Strategies](#)

[14.4 Aggregate Planning in Services](#)

[14.5 Mathematical Approaches to Aggregate Planning](#)

[14.6 The Management Coefficient Model](#)

[14.7 Decision Rule](#)

[14.8 Yield Management](#)

[14.9 Chapter Summary & Review Questions](#)

[14.10 Key Terms](#)

[14.11 Case Study: Brothers Flooring](#)

14.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Define aggregate planning and its relationship to Sales and Operations Planning (S&OP).
- Identify the key inputs and objectives of aggregate planning.
- Compare and contrast different aggregate planning strategies: chase, level, and mixed.
- Apply chase, level, and mixed strategies to a given scenario and calculate the total cost for each.
- Describe mathematical approaches to aggregate planning, including linear programming and the transportation model.
- Formulate a linear programming model for a simple production planning problem.
- Utilize the transportation method to determine an aggregate production plan.
- Explain the management coefficient model and decision rules in aggregate planning.
- Apply the management coefficient model to adjust workforce levels based on forecasted demand and managerial judgment.
- Describe aggregate planning in the service sector and the factors to consider.

14.1 INTRODUCTION

Aggregate Planning and Sales and Operations Planning (S&OP) are foundational processes in operations management, designed to align supply and demand over a medium-term horizon. These processes play a pivotal role in ensuring that an organization can meet market demand efficiently while optimizing the use of financial and operational resources.

The primary objective of Aggregate Planning and S&OP is to develop a unified, consensus-driven business plan that integrates demand forecasting, supply capabilities, and financial goals. In essence, aggregate planning evaluates projected market demand over a defined period and formulates a strategy to fulfill that demand through coordinated production and distribution, while minimizing costs and resource utilization (Oracle, 2025).

The Aggregate Planning and S&OP process typically follows these key steps:

1. *Data Gathering*: Collect and analyze historical sales data to identify trends and generate reliable forecasts.
2. *Demand Planning*: Refine forecasts by incorporating market intelligence, promotional activities, and anticipated product launches.
3. *Supply Planning*: Evaluate available capacity, inventory levels, and operational constraints to determine feasible supply strategies.
4. *Plan Reconciliation*: Align demand and supply plans with financial objectives, identifying and resolving any discrepancies.
5. *Executive S&OP Meeting*: Review, finalize, and approve the integrated plan at the executive level, ensuring organizational alignment and commitment.

14.2 CONCEPT AND HORIZON OF AGGREGATE PLANNING

Aggregate Planning and Sales and Operations Planning (S&OP) are interrelated and complementary processes within operations management. While aggregate planning focuses on developing production strategies that optimize resource utilization to meet forecasted demand, it does so at an aggregate level, typically considering product families rather than individual items. S&OP, on the other hand, is a broader, cross-functional process that integrates inputs from sales, operations, and finance to produce a unified, organization-wide plan (UKEssays, 2018).

Both processes are heavily dependent on accurate forecasting and capacity planning. Demand forecasts serve as a foundational input, enabling planners to anticipate future demand patterns and adjust production and resource levels accordingly.

As discussed in [Chapter 3](#), forecasting supports decision-making across three planning horizons:

- **Long-term (Strategic):** Typically spanning 1 to 5 years, these forecasts guide top management in making strategic decisions such as capacity expansion, new product development, and capital investments.
- **Medium-term (Tactical):** Covering 3 to 18 months, this horizon supports aggregate planning and S&OP activities. Operations managers use these forecasts to align production plans with fluctuating market demand.
- **Short-term (Operational):** Ranging from daily to six months, short-term forecasts help supervisors and operations managers schedule production activities, manage inventory, and coordinate job sequencing and order dispatching.

Planning Horizons and Decision Scope

Plan Time Horizon	Planners Involved	Plan Scope	Sample Decisions
Long-term (Strategic): 1–5 years	Top management	Strategic capacity planning	New product development, capital investment
Medium-term (Tactical): 3–18 months	Operations managers, S&OP team	Aggregate and S&OP planning	Production planning, budgeting
Short-term (Operational): Daily–6 months	Operations managers, supervisors	Short-term scheduling and control	Job sequencing, order scheduling, and dispatching

Aggregate planning and S&OP also involve evaluating current capacity and identifying strategies to adjust it in response to demand fluctuations. This includes both external and internal considerations:

- **External Factors:** These are largely market-driven and include changes in customer demand, which are often beyond the direct control of the firm. While businesses may attempt to influence demand through promotions, backordering, or product mix adjustments, such strategies are typically short-term and may carry risks such as lost sales or customer dissatisfaction.
- **Internal Factors:** These are within the firm's control and include adjustments to inventory levels, workforce size and skills, production rates, and subcontracting. Effective aggregate planning enables firms to manage these internal levers efficiently.

To be successful, aggregate planning requires access to accurate and timely information, including:

- Demand forecasts
- Inventory levels
- Workforce availability and costs
- Production capacity
- Subcontracting and overtime options
- Cost data related to inventory, hiring/firing, stockouts, and more

Using this information, the goals of aggregate planning are to:

1. Balance production rates, workforce levels, and inventory
2. Minimize total operational costs while meeting demand
3. Enhance customer service levels

4. Stabilize production and workforce utilization
5. Provide top management with a clear, data-driven view of the business

14.3 AGGREGATE PLANNING STRATEGIES

Effective aggregate planning relies on selecting appropriate strategies to manage capacity in response to forecasted demand. As discussed in [Chapter 4](#), capacity strategies serve as both operational and strategic levers that influence an organization's competitive position and long-term success. Common capacity strategies include:

- **Leading Capacity Strategy:** Adding capacity in anticipation of demand.
- **Following Capacity Strategy:** Increasing capacity only after demand has been realized.
- **Tracking Capacity Strategy:** Incrementally adjusting capacity to match demand trends.

While these strategies are typically strategic in nature, aggregate planning applies similar principles at an operational level. The three primary strategies used in aggregate planning are:

1. **Chase Strategy:** Adjusts production rates and workforce levels to match demand fluctuations precisely.
2. **Level Strategy:** Maintains a constant production rate and workforce, using inventory to buffer demand variability.
3. **Mixed Strategy:** Combines elements of both chase and level strategies, often incorporating overtime, subcontracting, or inventory adjustments.

In addition to these qualitative approaches, several quantitative methods are employed in aggregate planning, including:

- Linear Programming
- Transportation Models
- Management Coefficient Models
- Decision Rules based on Decision Theory



Example

To better understand these methods, let us consider a firm with the following six-month demand forecast:

Month	1	2	3	4	5	6
Demand (units)	1000	1200	1500	900	1100	1300

Operational Parameters:

- Regular production capacity: 1000 units/month
- Regular workforce: 50 workers
- Regular production cost: \$10/unit
- Overtime cost: \$15/unit
- Hiring cost: \$200/worker
- Layoff cost: \$250/worker
- Inventory holding cost: \$2/unit/month
- Subcontracting cost: \$12/unit

The firm evaluates three strategies to meet demand:

a) Chase Strategy

This strategy aligns production directly with monthly demand by adjusting workforce levels. It minimizes inventory but incurs costs related to hiring and layoffs.

Month	Demand	Regular Production	Workforce level	Hire/Layoff	Production Cost	Labor Cost	Total Cost
1	1000	1000	50	0	\$10,000	\$ –	\$10,000
2	1200	1200	60	Hire 10	\$12,000	\$2,400	\$14,000
3	1500	1500	75	Hire 15	\$15,000	\$4,800	\$18,000
4	900	900	45	Layoff 30	\$9,000	\$ –	\$16,500
5	1100	1100	55	Hire 10	\$11,000	\$1,200	\$13,000
6	1300	1300	65	Hire 10	\$13,000	\$2,400	\$15,000
							\$86,500

Total Cost: \$86,500

b) Level Strategy

Adopting a Level strategy, the firm maintains a constant (level) production rate and workforce, using inventory to absorb demand fluctuations. In some months, the production level might be more or less than the forecasted demand in that month. If the firm produces more than the demand, the excess production will be stored in a warehouse as inventory. This inventory might be carried from month to month at a cost known as holding cost or inventory carryover cost. If the production happens to be less than the projected demand, the gap is filled by taking some of the inventory and adding it to the month's production, so the demand is met. The total cost associated with this strategy is comprised of production cost and inventory holding cost, as shown in the following table.

Here, the firm maintains a constant production rate of 1167 units/month (based on the total demand of 7000 units over six months). Inventory is used to absorb demand fluctuations.

14.4 AGGREGATE PLANNING IN SERVICES

Aggregate planning in service organizations presents unique challenges compared to manufacturing due to two key characteristics:

1. *Services cannot be inventoried* – they are produced and consumed simultaneously.
2. *Backlogging is often not feasible* – customers may be unwilling to wait, resulting in a potential loss of business.

As a result, service-based aggregate planning focuses primarily on *managing capacity and demand in real time*. While service firms vary in the nature of their offerings, they typically follow similar planning steps. For instance, an accounting firm might approach aggregate planning as follows:

1-Demand Forecasting

Estimate workload based on seasonal patterns such as tax filing periods or audit cycles.

2-Capacity Planning

Assess staffing needs, including full-time employees and potential temporary hires.

3-Scheduling

Allocate tasks to ensure balanced workloads and timely completion of client deliverables.

4-Cross-Training

Equip staff with diverse skills to increase flexibility and responsiveness.



Example: Accounting Firm

Suppose an accounting firm anticipates the following demand (in billable hours) over the next four months:

Month	1	2	3	4
Demand (hours)	2000	3500	4000	2500

Available Resources:

- Full-time staff: 10 accountants
- Capacity per accountant: 160 billable hours/month
- Temporary staff cost: \$50/hour

Planning Calculations:

1. Total capacity (full-time staff):
 $10 \text{ accountants} \times 160 \text{ hours/month} \times 4 \text{ months} = 6,400 \text{ hours}$
2. Total forecasted demand:
 $2000 + 3500 + 4000 + 2500 = 12,000 \text{ hours}$
3. Shortfall in capacity:
 $12,000 - 6,400 = 5,600 \text{ hours}$
4. Cost of meeting the shortfall with temporary staff:
 $5,600 \times \$50 = \$280,000$

Strategic Considerations

The firm must now evaluate its options:

- Hire temporary staff to cover the shortfall, incurring additional costs.
- Use overtime, if feasible, to increase capacity without hiring.
- Turn down work, which may reduce revenue and risk losing clients.

Each option involves trade-offs between cost, service quality, and client satisfaction. The optimal strategy will depend on the firm's priorities, such as maintaining client relationships, managing labour costs, and ensuring timely service delivery.

14.5 MATHEMATICAL APPROACHES TO AGGREGATE PLANNING

Mathematical models provide a structured and quantitative foundation for aggregate planning, enabling decision-makers to optimize resource allocation while meeting demand constraints. Two widely used methods are Linear Programming (LP) and the Transportation Model.

Linear Programming

Linear programming is a powerful optimization technique used to minimize total production costs while satisfying demand and capacity constraints. Consider the following example:



Example

Problem Context

A company produces two special-order products, A and B, with unit production costs of \$50 and \$70, respectively. Due to commitments to other products, the company has limited production capacity for special orders over the next three months:

Month	Available Capacity (units)
1	100
2	120
3	110

Projected demand for products A and B is:

Month	Demand A	Demand B
1	20	20
2	40	30
3	50	40

Formulation

Let:

- x_1, x_2, x_3 : Units of Product A produced in Months 1, 2, and 3
- y_1, y_2, y_3 : Units of Product B produced in Months 1, 2, and 3

Objective Function:

Minimize total cost:

$$Z = 50(x_1 + x_2 + x_3) + 70(y_1 + y_2 + y_3)$$

Subject to Constraints.

Capacity Constraints:

- $x_1 + y_1 \leq 100$
- $x_2 + y_2 \leq 120$
- $x_3 + y_3 \leq 110$

Demand Constraints:

- $x_1 \geq 20, x_2 \geq 40, x_3 \geq 50$
- $y_1 \geq 20, y_2 \geq 30, y_3 \geq 40$

Non-negativity:

- $x_i, y_i \geq 0$ for all i

This problem can be solved using the Simplex Method or other LP solvers, as discussed in [Chapter 16](#).

Farnsworth Transportation Model

The transportation model is particularly useful when demand can be met through multiple sources, such as **regular production, overtime, subcontracting**, and **inventory carryover**. It aims to minimize total cost while satisfying demand across multiple periods.



Example

Problem Context

A hardwood flooring manufacturer must meet the following monthly demand for solid oak flooring:

Month	Demand (m ²)
1	5,000
2	15,000
3	20,000
4	5,200

Available Resources and Costs:

- *Beginning Inventory*: 500 m²
- *Regular Production*: 5,000 m²/month at \$40/m²
- *Overtime Capacity*: 5,000 m²/month at \$75/m²
- *Subcontracting*: 4,000 m²/month at \$85/m²
- *Inventory Holding Cost*: \$2/m²/month

The three measures available to the company are regular production, using overtime, and subcontracting. Within the context of the transportation model, we can assume that these measures are the sources of supply for which we have four market demands, as shown in the following table.

#NAME?		USED								Unused	Capacity
		Month 1		Month 2		Month 3		Month 4			
	Bgining Inventory	500	42		44		46		48	0	500
Period 1	Regular Production	4500	40		42		44		46	500	5000
	Overtime		50		52		54		56	0	5000
	Subcontracting		60		62	2000		64		2000	4000
Period 2	Regular Production			5000	40		42		44	0	5000
	Overtime			5000	50		52		54	0	5000
	Subcontracting				60	4000		62		0	4000
Period 3	Regular Production					5000	40		42	0	5000
	Overtime					5000	50		44	0	5000
	Subcontracting					4000	60		46	0	4000
Period 4	Regular Production							5000	40	0	5000
	Overtime							200	50	4800	5000
	Subcontracting								60	4000	4000
		5,000		15,000		20,000		5,200			

[Downloadable Excel File](#)

Approach

The goal is to allocate production and inventory resources across four months to minimize total cost. The steps include:

1. *Utilize Beginning Inventory:* Use the 500 m₂ from the previous month to avoid

holding costs.

2. *Prioritize Low-Cost Options*: Use regular production first, followed by overtime and subcontracting.
3. *Carry Over Excess Capacity*: If demand is unmet in a given month, use surplus from previous months.

Monthly Breakdown

- **Month 1:**

- 500 m_2 from inventory
- 4,500 m_2 from regular production
- **Total:** 5,000 m_2 (demand met)

- **Month 2:**

- 5,000 m_2 from regular production
- 5,000 m_2 from Month 1 overtime (carried forward)
- 5,000 m_2 from overtime
- **Total:** 15,000 m_2 (demand met)

- **Month 3:**

- 5,000 m_2 from regular production
- 5,000 m_2 from overtime
- 4,000 m_2 from subcontracting
- 6,000 m_2 from subcontracting carried out in previous months
- **Total:** 20,000 m_2 (demand met)

- **Month 4:**

- 5,000 m_2 from regular production
- 200 m_2 from overtime
- **Total:** 5,200 m_2 (demand met)

Cost Calculation

By summarizing the quantities used from each source and applying the respective costs, the total cost of the four-month plan is:

Capacity used	calculation details				Cost
	Month 1	Month 2	Month 3	Month 4	
Inventory holding	$500 * \$40$				\$ 20,000
Regular Production	$4500(\$40) +$	$5000x(\$40) +$	$5000(\$40) +$	$5000(\$40)$	\$ 780,000
Overtime	$5000(\$52) +$	$(5000)(\$50) +$	$(5000)(\$50) +$	$(200)(\$50)$	\$ 770,000
Subcontracting	$2000(\$64) +$	$4000(\$62) +$	$4000(\$60) +$		\$ 616,000
					\$ 2,186,000

Image Description

Capacity used	Calculation details				Cost
	Month 1	Month 2	Month 3	Month 4	
	Inventory holding	$500 * \$40$			\$20,000
Regular Production	$4500(\$40) +$	$5000(\$40) +$	$5000(\$40) +$	$5000(\$40)$	\$780,000
Overtime	$5000(\$52) +$	$5000(\$50) +$		$200(\$50)$	\$770,000
Subcontracting	$2000(\$64) +$	$4000(\$62) +$	$4000(\$60) +$		\$616,000
					\$2,186,000

Total Cost: \$2,186,000

This solution meets all demand requirements while minimizing costs through optimal use of available resources.

14.6 THE MANAGEMENT COEFFICIENT MODEL

The Management Coefficient Model, developed by E.H. Bowman, is a hybrid approach to aggregate planning that integrates quantitative analysis with managerial judgment. Unlike purely mathematical models, this method acknowledges the value of experience, intuition, and contextual understanding in decision-making.

At its core, the model utilizes historical data and regression analysis to establish relationships between key planning variables, including demand and workforce levels. However, it also allows managers to adjust model parameters based on recent developments, strategic priorities, or operational insights that may not be reflected in historical trends.



Examples

Consider a manufacturing company that aims to determine the optimal workforce levels for the next six months based on forecasted demand.

Month	Demand (Units)	Workforce (Employees)
1	10,000	100
2	12,000	110
3	11,000	105
4	13,000	115
5	14,000	120
6	12,500	112

Historical data have been analyzed using simple linear regression, resulting in the following relationship:

- $\text{Workforce} = 50 + 0.005 \times \text{Demand}$

This equation suggests that for every unit increase in demand, 0.005 additional workers are required, starting from a base of 50 employees. However, the production manager believes that recent efficiency improvements—such as automation or process optimization—will allow the company to meet demand with fewer workers. Based on this insight, the coefficient is adjusted to reflect improved productivity:

- $\text{Adjusted Workforce} = 50 + 0.004 \times \text{Demand}$

Forecast-Based Workforce Planning

Using the adjusted model and the forecasted demand for the next six months, the company calculates the required workforce as follows:

Month	Forecasted Demand (Units)	Workforce Requirement
7	13,500	$50 + 0.004 \times 13,500 = 104$ employees
8	14,000	$50 + 0.004 \times 14,000 = 106$ employees
9	15,000	$50 + 0.004 \times 15,000 = 110$ employees
10	14,500	$50 + 0.004 \times 14,500 = 108$ employees
11	13,000	$50 + 0.004 \times 13,000 = 102$ employees
12	12,500	$50 + 0.004 \times 12,500 = 100$ employees

Model Advantages

The Management Coefficient Model offers several benefits:

- *Flexibility*: Allows for adjustments based on managerial insight, making it adaptable to changing business conditions.
- *Balance*: Combines data-driven rigour with human expertise, enhancing the relevance and reliability of planning decisions.
- *Practicality*: Particularly useful when historical data does not fully capture recent changes in technology, efficiency, or market dynamics.

This model is especially valuable in environments where quantitative models alone may be insufficient, and where managerial experience plays a critical role in interpreting and applying data (Remus, 1978; Bowman, 1963).

14.7 DECISION RULE

In **decision theory**, a decision rule is a formal function that maps observed data or conditions to a specific course of action. It plays a central role in fields such as statistics, economics, and game theory, where decisions must be made under uncertainty. A decision rule typically operates within the framework of a loss function, which quantifies the cost or penalty associated with each possible action under various states of nature. The goal is to select the action that minimizes expected loss.

Linear Decision Rule (LDR)

The **Linear Decision Rule (LDR)** is a mathematical approach to aggregate production planning developed by Holt, Modigliani, Muth, and Simon in the 1960s. It provides a systematic method for determining optimal monthly production levels, workforce size, and inventory levels, with the objective of minimizing total operational costs.

LDR is particularly useful in environments where demand fluctuates over time and where costs are associated with:

- Changing production rates (e.g., hiring, layoffs)
- Holding inventory
- Using overtime or idle capacity

The Linear Decision Rule uses a set of linear equations derived from cost functions and operational constraints. These equations relate:

- Forecasted demand
- Current inventory levels
- Workforce availability
- Production capacity

The model then computes the optimal values for decision variables (e.g., production quantity, workforce size) that minimize the total cost while satisfying demand and operational constraints. Key Features of LDR are;

- **Cost Minimization:** Balances trade-offs between inventory holding, labour adjustments, and production changes.
- **Dynamic Planning:** Adjusts decisions month-by-month based on updated forecasts and system states.
- **Managerial Relevance:** Offers a structured yet flexible tool for production managers to make informed decisions.

LDR is particularly effective in industries with:

- Seasonal or cyclical demand.
- High labour or inventory costs.
- Need for coordinated planning across multiple time periods.

It remains a foundational technique in operations research and is often integrated into more complex planning systems such as ERP and advanced planning and scheduling (APS) tools (Holt, 1955).

14.8 YIELD MANAGEMENT

Yield Management is a specialized form of aggregate planning that focuses on maximizing revenue through dynamic pricing and strategic capacity allocation. It is particularly effective in industries with perishable inventory, where unsold capacity cannot be stored or reused (such as airlines, hotels, car rentals, and event venues).

The core principle of yield management is to sell the right product to the right customer at the right time and for the right price. This approach relies heavily on data-driven decision-making and involves four key components:

1. *Customer Segmentation*: Differentiating customers based on price sensitivity and purchasing behaviour.
2. *Variable Pricing*: Adjusting prices dynamically in response to demand fluctuations.
3. *Inventory Control*: Allocating limited capacity (e.g., hotel rooms or airline seats) across customer segments to maximize revenue.
4. *Demand Forecasting*: Predicting future demand to inform pricing and allocation decisions.



Hotel Example

Consider a hotel with 100 rooms and two customer segments:

- Business travellers: Less price-sensitive, willing to pay premium rates.
- Leisure travellers: More price-sensitive, attracted by discounts.

Assume the following pricing and cost structure:

- Standard room rate: \$200
- Discounted rate: \$150
- Cost per occupied room: \$50

Scenario 1: Without Yield Management

Segment	Rooms Sold	Rate	Revenue
Business Travelers	60	\$200	\$12,000
Leisure Travelers	20	\$150	\$3,000
Total Revenue			\$15,000
Total Cost	80 rooms × \$50 = \$4,000		
Profit			\$11,000

Scenario 2: With Yield Management

Segment	Rooms Sold	Rate	Revenue
Business Travelers	70	\$220	\$15,400
Leisure Travelers	30	\$140	\$4,200
Total Revenue			\$19,600
Total Cost	100 rooms $\times$ \$50 = \$5,000		
Profit			\$14,600

- Profit Increase: $\$14,600 - \$11,000 = \$3,600$
- Percentage Increase: $3,600/11,000 \times 100 \approx 32.7\%$

Strategic Implications

Yield management enables firms to:

- Lower prices during low-demand periods to attract price-sensitive customers.
- Raise prices during high-demand periods to capture more value from less price-sensitive segments.
- Optimize occupancy and average revenue per unit (e.g., per room or seat).

By leveraging forecasting, segmentation, and pricing analytics, businesses can significantly enhance profitability. The key is to balance occupancy and pricing to maximize total revenue, rather than simply maximizing volume or minimizing cost.

14.9 CHAPTER SUMMARY & REVIEW



Summary

This chapter outlines the importance of aligning supply and demand to create efficient, cost-effective business plans that integrate sales, operations, and financial objectives. It distinguishes between planning horizons: long-term (strategic), medium-term (tactical), and short-term (operational). It discusses how aggregate planning works with Sales and Operations Planning (S&OP) to manage resources and meet forecasted demand. Three core strategies are introduced: the chase strategy (matching production to demand through workforce changes), the level strategy (keeping production steady while using inventory to buffer demand fluctuations), and the mixed strategy (combining elements of both). The chapter illustrates how these strategies compare in cost and operational impact, showing that while the level strategy often minimizes costs, other factors, such as workforce stability and customer service, also guide selection.

Mathematical approaches to aggregate planning, including linear programming and the transportation model, provide quantitative methods for minimizing costs and optimizing resource allocation across time periods. The Management Coefficient Model (blending data with managerial judgment), decision rules like the Linear Decision Rule (LDR) for dynamic planning, and yield management, a revenue-maximization technique, are explained as tools used in industries with perishable inventory (e.g., airlines, hotels). Overall, aggregate planning emerges as both a strategic and operational process, balancing costs, workforce considerations, inventory, and customer satisfaction to achieve organizational goals.

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Review Questions

1. In your own words, what does aggregate planning mean, and why do businesses need it?
2. How does aggregate planning work alongside Sales and Operations Planning (S&OP) to help a company stay on track with its goals?
3. What kinds of information (like forecasts, workforce, or costs) does a company need before it can create an aggregate plan?
4. What is the main goal of aggregate planning, and how does it help a company balance saving money and keeping customers happy?
5. What's the difference between the chase, level, and mixed strategies? Which one do you think would be hardest for workers, and why?
6. If you owned a company that sold winter jackets, which planning strategy would you choose (chase, level, or mixed), and why?
7. How can math tools like linear programming help businesses make better decisions about production and costs?
8. Why might a manager's experience or "gut feeling" be useful in planning, even when numbers and formulas are available?
9. Why is it harder to plan for services (like a restaurant or accounting firm) compared to making products (like shoes or phones)?
10. How do airlines or hotels use yield management (changing prices depending on demand) to make more money, and have you seen this happen in real life?

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create ten discussion questions with simple wording based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter. reviewed by authors.

14.10 CHAPTER PROBLEMS



Chapter Problems

1. A company has the following demand forecast for the next six months:

Month	1	2	3	4	5	6
Demand (Units)	1200	1500	1800	1600	1400	1300

The company also provides the following operational data:

- Regular production capacity: 1400 units/month
- Regular time cost: \$12/unit
- Overtime cost: \$18/unit
- Inventory holding cost: \$3/unit/month
- Hiring cost: \$300/worker
- Layoff cost: \$400/worker

Develop an aggregate plan using the chase strategy, level strategy, and a mixed strategy. Calculate the total cost for each strategy and recommend the most suitable option based on cost and operational considerations.

2. Explain how linear programming can be applied to aggregate planning. Formulate a basic linear programming model for a production planning problem, including an objective function and constraints.
3. Describe the transportation model. How can it be used to optimize resource allocation in aggregate planning across multiple time periods?
4. What is the Management Coefficient Model? How does it integrate historical data

and managerial judgment in workforce planning?

5. A company wants to use the Management Coefficient Model to plan its workforce for the next four months. Historical data is provided below:

Month	1	2	3	4	5	6
Demand (Units)	1000	1200	1500	1300	1100	900
Workforce (Employees)	60	70	80	75	65	55

6. The company's forecasted demand for the next four months is:

Month	7	8	9	10
Demand (Units)	1400	1600	1300	1100

Use the Management Coefficient Model to estimate the required workforce for each of the next four months.

7. What are decision rules in the context of aggregate planning? Discuss how they are used to guide production and workforce decisions under uncertainty.
8. Discuss the unique considerations for aggregate planning in service organizations. How do factors such as non-inventoriable services and customer sensitivity to delays influence planning decisions?

14.11 CASE STUDY: BROTHERS FLOORING



Case Study: Brothers Flooring Exercises

Ali and Abbas Hamdouni, two brothers, launched a residential flooring business specializing in tile, laminate, and hardwood installations. From the outset, they prioritized high-quality workmanship and closely supervised their team of three employees.

Recently, Ali was diagnosed with advanced arthritis and advised by his physician to significantly reduce physical labour. As a result, Abbas assumed full responsibility for managing operations and completing contracts. However, Ali agreed to assist during peak periods and would be compensated at a rate of \$125 per square meter (m²) for any flooring he installs.

With Ali on reduced duty, Abbas must now ensure that all accepted contracts—each with a fixed start and completion date—are fulfilled over the next six months. The monthly installation targets are summarized below:

Months	August	September	October	November	December	January
Est. Volume of work (in square meters)	600	500	1000	1200	650	590

Workforce and Compensation Structure

Abbas met with the three employees and proposed the following plan:

- The team (including Abbas) will aim to install 640 m² per month, with each person responsible for 160 m².
 - Each employee will receive a flat salary of \$5,000/month.
 - Any employee installing more than 160 m² will earn overtime pay of \$62.50/m², capped at 240 m²/month.
 - Abbas emphasized maintaining quality: “You’ll have your jobs, with salary and overtime pay, but we don’t want to rush installs and lose quality.”
 - Ali reiterated his willingness to help during busy months and mentioned that business volume may increase next year, prompting Abbas to consider hiring an additional employee.
-

Questions

Abbas has asked for your help in answering two key questions:

1. Develop a six-month workforce and cost plan based on current staffing and Ali’s availability.
2. Evaluate whether hiring a new employee (at \$5,000/month) would be cost-effective during this period.

Solution

1. Six-Month Plan and Cost Analysis (Current Workforce + Ali)

Month	Demand (m ²)	Employees	Regular Install (m ²)	Regular Cost	Overtime (m ²)	Overtime Cost	Ali's Install (m ²)	Ali's Cost
Aug	600	4	640	\$20,000	0	\$0	0	\$0
Sep	500	4	640	\$20,000	0	\$0	0	\$0
Oct	1,000	4	640	\$20,000	320	\$20,000	40	\$5,000
Nov	1,200	4	640	\$20,000	320	\$20,000	240	\$30,000
Dec	650	4	640	\$20,000	10	\$625	0	\$0
Jan	590	4	640	\$20,000	0	\$0	0	\$0

Total Cost:

- Regular Salaries: \$120,000
- Overtime: \$40,625
- Ali's Installations: \$35,000
- Grand Total: \$195,625

2. Evaluation of Hiring an Additional Employee

Assuming a fifth employee is hired at \$5,000/month (totalling \$30,000 over six months), the revised plan would look like this:

Month	Demand (m ²)	Employees	Regular Install (m ²)	Regular Cost	Overtime (m ²)	Overtime Cost	Ali's Install (m ²)	Ali's Cost
Aug	600	5	800	\$25,000	0	\$0	0	\$0
Sep	500	4	800	\$25,000	0	\$0	0	\$0
Oct	1,000	4	800	\$25,000	200	\$12,500	0	\$0
Nov	1,200	4	800	\$25,000	400	\$25,000	0	\$0
Dec	650	4	800	\$25,000	0	\$625	0	\$0
Jan	590	4	800	\$25,000	0	\$0	0	\$0

Total Cost:

- Regular Salaries: \$150,000
- Overtime: \$37,500
- Ali's Installations: \$0
- Grand Total: \$187,500

Recommendation

- Cost Savings: Hiring a fifth employee reduces total cost by \$8,125.
- Employee Morale: Existing employees earned significant overtime in October and November. Hiring may reduce their income and affect morale.
- Ali's Health: If Ali's condition improves, his availability could reduce the need for a new hire.
- Future Demand: If business volume increases next year, hiring may become necessary.

Conclusion: While hiring an additional employee offers modest cost savings, Abbas should weigh this against employee satisfaction, Ali's recovery, and future workload. A flexible approach—such as temporary help during peak months—may be more appropriate until demand stabilizes.

OpenAI. (2024, May 7). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Reviewed by authors.

14.12 KEY TERMS



Key Terms

- **Aggregate Planning and Sales and Operations Planning (S&OP)** are processes designed to align supply and demand over a medium-term horizon.
- **Capacity Planning:** assess staffing needs, including full-time employees and potential temporary hires.
- **Chase Strategy:** adjusts production rates and workforce levels to match demand fluctuations precisely.
- **Cross-Training:** equips staff with diverse skills to increase flexibility and responsiveness.
- **Decision Rule:** a formal function that maps observed data or conditions to a specific course of action.
- **Demand Forecasting:** estimates workload based on seasonal patterns such as tax filing periods or audit cycles.
- **External Factors:** largely market-driven influences, including changes in customer demand, that are often beyond the firm's direct control; short-term tactics like promotions or backordering may help but carry risks such as lost sales or dissatisfaction.
- **Following Capacity Strategy:** increases capacity only after demand has been realized.
- **Internal Factors:** levers within the firm's control, including inventory levels, workforce size and skills, production rates, and subcontracting, managed through effective aggregate planning.
- **Leading Capacity Strategy:** adds capacity in anticipation of demand.

- **Level Strategy:** maintains a constant production rate and workforce, using inventory to buffer demand variability.
- **Linear Decision Rule (LDR):** a mathematical approach to aggregate production planning for determining optimal monthly production, workforce, and inventory levels to minimize total operational costs.
- **Long-term (Strategic):** typically spans 1 to 5 years and guides decisions such as capacity expansion, new product development, and capital investments.
- **Management Coefficient Model:** a hybrid aggregate-planning approach that integrates quantitative analysis with managerial judgment, acknowledging the value of experience and context.
- **Medium-term (Tactical):** covers 3 to 18 months and supports aggregate planning and S&OP activities to align production with fluctuating demand.
- **Mixed Strategy:** combines elements of chase and level strategies, often using overtime, subcontracting, or inventory adjustments.
- **Scheduling:** allocates tasks to ensure balanced workloads and timely completion of deliverables.
- **Short-term (Operational):** ranges from daily to six months, helping to schedule production, manage inventory, and coordinate job sequencing and dispatching.
- **Tracking Capacity Strategy:** incrementally adjusts capacity to match demand trends.
- **Yield Management:** a specialized form of aggregate planning focused on maximizing revenue through dynamic pricing and strategic capacity allocation, especially for perishable inventory.

CHAPTER 15: SCHEDULING

Chapter Overview

[15.0 Learning Outcomes](#)

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[15.2 Scheduling in Manufacturing](#)

[15.3 Scheduling Challenges in Manufacturing](#)

[15.4 Resource Assignment in Operations Scheduling](#)

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[15.9 Key Terms](#)

15.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

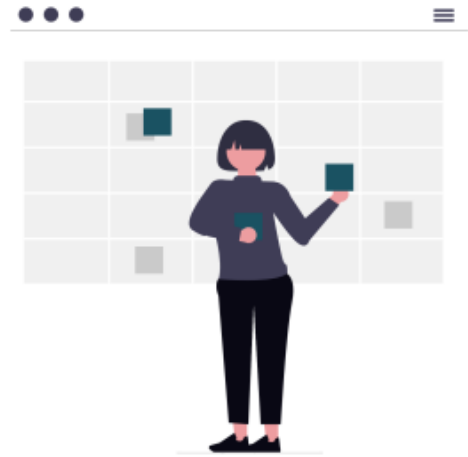
- Explain the importance of job scheduling in operations management.
- Identify different job scheduling rules and their characteristics (e.g., FCFS, SPT, EDD, CR).
- Apply various job scheduling rules to a given set of jobs and calculate performance metrics.
- Compare the performance of different scheduling rules based on the calculated metrics.
- Determine appropriate scheduling rules for different operational objectives (e.g., minimizing flow time, minimizing tardiness).
- Analyze the impact of job sequencing on waiting times and overall efficiency.
- Explain how to schedule jobs on multiple machines.
- Apply techniques for assigning resources (e.g., cranes) to tasks (e.g., construction sites) to optimize allocation.

15.1 INTRODUCTION

Scheduling is the process of determining the sequence and timing of jobs to be completed within a short-term planning horizon, typically within a day. This process is fundamental to both manufacturing and service operations, where it involves the allocation of limited resources, such as labour, time, or equipment, to specific tasks. When applied in this context, it is referred to as operations scheduling.

Effective scheduling aims to achieve three primary objectives: minimizing job completion time (makespan), reducing work-in-progress inventory, and maximizing the utilization of available resources. These goals are critical for enhancing operational efficiency and responsiveness.

To build a comprehensive understanding of operations scheduling, this chapter first explores its application in manufacturing environments, followed by its role in service operations. It also introduces the quantitative methods commonly used to support scheduling decisions in each context.



“Scheduling” by Undraw, [Undraw License](#)

15.2 SCHEDULING IN MANUFACTURING

In manufacturing operations, **scheduling** refers to the process of assigning a sequence of jobs to various machines involved in the production process. It determines the order in which tasks are executed and how resources are allocated to ensure efficient workflow.



Example: Dressing Dolls

To illustrate, consider a simplified example involving the dressing of dolls. Suppose the dressing process consists of three sequential tasks:

- a. putting on pants,
- b. putting on socks, and
- c. putting on shoes.

Assume there are three machines, each dedicated to one task:

- *Machine 1* handles pants,
- *Machine 2* handles socks, and
- *Machine 3* handles shoes.

Now, consider three identical dolls—A, B, and C—that must undergo the same dressing process. Figure 15.2.1 illustrates this scenario. Since all dolls follow the same sequence of operations, determining the job sequence is relatively straightforward. However, scheduling becomes significantly more complex when products require different sequences of operations.

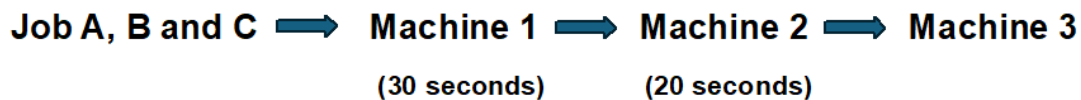


Figure 1: m jobs requiring n Machines in the same sequence to be completed

Figure 15.2.1: m jobs requiring n machines in the same sequence to be completed.

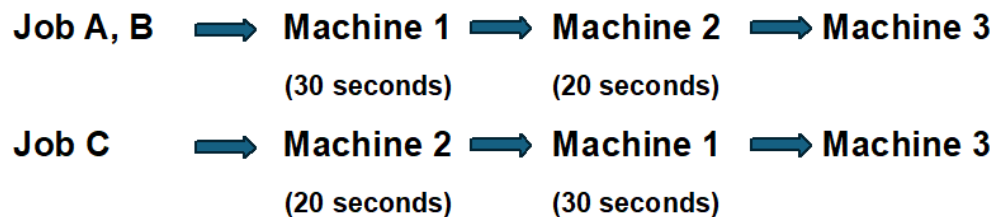


Figure 2: m jobs requiring n Machines in the different orders to be completed

Figure 15.2.2 presents such a case: dolls A and B follow the sequence pants → socks → shoes, while doll C follows socks → pants → shoes. This variation introduces a scheduling challenge.



Example Cont: Dressing Dolls

For example, suppose doll A begins the process and takes 30 seconds on Machine 1 (pants), followed by doll B. Simultaneously, doll C starts on Machine 2 (socks), taking 20 seconds. After 20 seconds, doll C is ready for Machine 1.

At this point, a decision must be made:

- Should doll C wait until only doll A finishes on Machine 1 (resulting in a 10-second wait)?
- Or should it wait for both A and B to finish (resulting in a 50-second wait)?

As the number of jobs increases, such decisions become more critical. The complexity of scheduling in manufacturing depends on several key factors:

1. Sequence of Operations

The order in which tasks are performed can vary across jobs. In the doll example, some may follow pants → socks → shoes, while others follow socks → pants → shoes. This variability is more common in **batch production systems**, where different products require different operations. In contrast, **mass production systems**—such as a car wash where every car undergoes washing, rinsing, and drying—have standardized sequences, making scheduling simpler.

2. Number of Jobs

Batch production typically involves a variety of jobs, each produced in low volumes. Each job may differ in terms of:

- Required operations,
- Sequence of tasks,
- Processing time at each machine.

For instance, in a cake manufacturing facility, a chocolate cake and a vanilla cake may use the same machines but differ in ingredients, operation sequences, and processing times. This diversity increases setup times and waiting periods, thereby complicating scheduling and reducing productivity.

3. Number of Machines

If only one machine is available, scheduling involves assigning jobs to that single resource. However, most manufacturing systems involve multiple machines, each performing different operations. A manager must decide:

- Whether operations can be grouped and performed on a single machine, or
- Whether they must be distributed across multiple machines due to their distinct nature.

Another common scenario involves multiple jobs being processed on a set of similar machines, requiring careful coordination to optimize throughput and minimize idle time.

“[18 Scheduling: Importance and Methods in Manufacturing](#)” from [Operations Management](#) by Vikas Singla is licensed under a [Creative Commons Attribution-NonCommercial 4.0 International License](#), except where otherwise noted.

15.3 SCHEDULING CHALLENGES IN MANUFACTURING

The following are different types of sequencing cases that have been discussed in this chapter:

- Scheduling of n jobs on a single machine
- Scheduling of n jobs on two machines
- Scheduling of n jobs on more than 2 machines

Scheduling of n Jobs on a Single Machine

In many manufacturing environments, *general-purpose machines* are used to perform different operations on various jobs. For example, a single drilling machine may be used to drill different hole sizes in multiple wooden boards. When multiple jobs are queued for the same machine, it becomes essential to determine the optimal processing sequence to improve efficiency and meet delivery deadlines.

Let's say there are five drilling jobs to be completed. The question becomes: *Which job should be processed first, and in what order should the others follow?*

Scheduling can be based on several criteria, such as: *First Come, First Served (FCFS)*, *Shortest Processing Time (SPT)* and *Earliest Due Date (EDD)*.

In this section, we focus on two widely used priority rules:

1. Earliest Due Date (EDD) Rule

Jobs are scheduled in the order of their due dates. The job with the *earliest delivery requirement* is processed first, followed by the next earliest, and so on.

2. Shortest Processing Time (SPT) Rule

Jobs are scheduled based on their *processing time*. The job that takes the **least time** is processed first, followed by the next shortest, and so on.

Manufacturing Firm Example

A manufacturing firm has five drilling jobs, each with a specific processing time and due date. All jobs are to be completed on the same drilling machine.

Figure 15.3.1 Drilling Jobs

	Processing time (hrs.)	Scheduled supply time (hrs.)
Cardboard 1	8	10
Cardboard 2	6	12
Cardboard 3	15	20
Cardboard 4	3	18
Cardboard 5	12	22



Example: Using EDD Rule

Jobs are sequenced based on their due dates. Suppose the order is: *Cardboards: 1, 2, 4, 3, 5*

We calculate the waiting time and completion time for each job. For example:

- **Cardboard 1** starts at 0 minutes and takes 8 minutes → completes at 8 minutes.
- **Cardboard 2** starts at 8 minutes, takes 6 minutes → completes at 14 minutes.
- And so on...

Figure 15.3.2 Drilling Jobs – EDD Rule

Cardboard	Start time	Processing time	End time	Supply time	Waiting time
1	0	8	8	10	$8 - 10 = 2$
2	8	6	14	12	$14 - 12 = 2$
4	14	3	17	18	$17 - 18 = -1$
3	17	15	32	20	$32 - 20 = 12$
5	32	12	44	22	$44 - 22 = 22$

If a job is completed before its due date, the difference is shown as a negative value, indicating early delivery.



Example: Using SPT Rule

Jobs are sequenced based on processing time. Suppose the order is: *Cardboards: 4, 2, 1, 5, 3*

- **Cardboard 4** starts at 0 minutes, takes 3 minutes → completes at 3 minutes.
- **Cardboard 2** starts at 3 minutes, takes 6 minutes → completes at 9 minutes.
- And so on...

Figure 15.3.3 Drilling Jobs – SPT Rule

Cardboard	Start time	Processing time	End time	Supply time	Waiting time
4	0	3	3	18	$3 - 18 = -15$
2	3	6	9	12	$9 - 12 = -3$
1	9	8	17	10	$17 - 10 = 7$
5	17	12	29	22	$29 - 22 = 7$
3	29	15	44	20	$44 - 22 = 22$

Comparison of Methods

- Total processing time (makespan) remains the same: 44 minutes
- Average job flow time:
 - $EDD = (8 + 14 + 17 + 32 + 44) / 5 = 23.0$ minutes
 - $SPT = (3 + 9 + 17 + 29 + 44) / 5 = 20.4$ minutes

Since the *SPT rule results in a lower average flow time, it is the preferred method in this case.*

Scheduling of n Jobs on Two Machines

In this scheduling scenario, multiple jobs must be processed *sequentially on two machines*, typically labelled Machine A and Machine B. Each job must first be processed on Machine A and then on Machine B, following a fixed technological sequence.



This situation is commonly addressed using **Johnson's Rule**, a method designed to minimize total processing time (makespan) for jobs passing through two machines.

Johnson's Rule: Steps

1. List the processing times of each job on both machines.
2. Identify the job with the shortest processing time among all remaining jobs.
 - If the shortest time is on Machine A, schedule that job as early as possible.
 - If the shortest time is on Machine B, schedule that job as late as possible.
 - In case of a tie, prioritize the job for early scheduling.
3. Repeat the process until all jobs are scheduled.



Example

Four jobs (A, B, C, D) need to be processed on Machines A and B. The processing times are as follows:

Figure 15.3.4 Jobs

Job	Machine A (min)	Machine B (min)
A	7	2
B	5	6
C	4	8
D	6	4

Step 1: The shortest processing time is 2 minutes (Job A on Machine B).

→ Schedule Job A last.

Step 2: Among the remaining jobs, the next shortest time is 4 minutes (Job C on Machine A).

→ Schedule Job C first.

Step 3: Next shortest is 5 minutes (Job B on Machine A).

→ Schedule Job B second.

Step 4: Only Job D remains. It is scheduled before Job A.

Final sequence: C → B → D → A

Figure 15.3.5 Jobs

Jobs	Machine 1			Machine 2			Waiting Time	
	Start Time	Process Time	End Time	Start Time	Process Time	End Time	Machine 1	Machine 2
C	0	5	5	5	6	11	0	5
B	5	6	11	11	8	19	$5 - 5 = 0$	$11 - 11 = 0$
D	11	7	18	19	4	23	$11 - 11 = 0$	$19 - 19 = 0$
A	18	3	21	23	2	25	$18 - 18 = 0$	$23 - 23 = 0$

Waiting Time and Visualization

Once the sequence is determined, the waiting time for each job on Machine B can be calculated by tracking when Machine B becomes available after Machine A finishes processing each job.

A Gantt chart or timeline diagram can be used to visually represent the job flow and idle times on each machine.

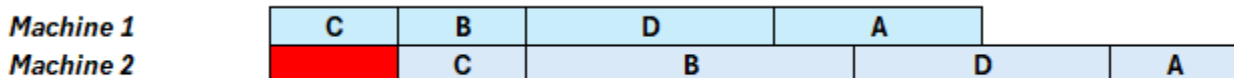
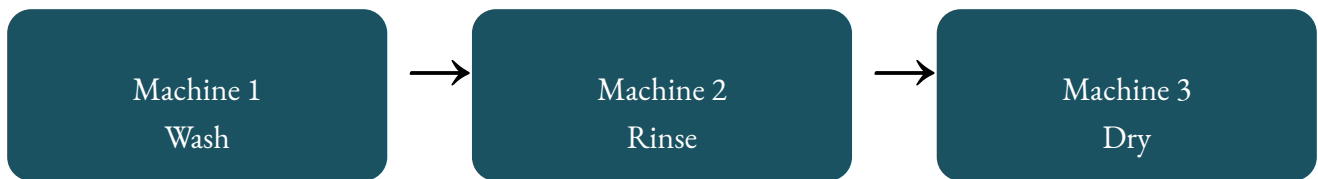


Figure 15.3.6 Waiting Times

Scheduling of n Jobs on More Than Two Machines

In some manufacturing environments, jobs must be processed sequentially on *more than two machines*. A special case of **Johnson's Rule** can be applied in such scenarios, provided certain conditions are met. This approach helps determine the optimal job sequence to minimize the total processing time, or **makespan**.



Car Wash Example

Consider a car wash operation where three machines are arranged in a fixed technological sequence—each dedicated to a specific task. Every car must pass through all machines in the same order. Similarly, in more complex manufacturing settings, jobs may need to be processed on *three or more machines* (e.g., $A \rightarrow B \rightarrow C \rightarrow D$).

Let's examine a case where four jobs (1, 2, 3, and 4) must be processed on four machines (A, B, C, and D) in the fixed sequence $A \rightarrow B \rightarrow C \rightarrow D$. The processing times (in minutes) for each job on each machine are provided in a table.

Figure 15.3.7 Car Wash Jobs

	Machines			
Jobs	A	B	C	D
1	58	14	14	48
2	30	10	18	32
3	28	12	16	44
4	64	16	12	42



Example: Steps for Applying Johnson's Rule to More Than Two Machines

Step 1: Identify the minimum processing time on the first machine (A) and the last machine (D).

- In this case:
- Minimum on A = 28 minutes
- Minimum on D = 32 minutes

Step 2: Find the maximum processing time on the intermediate machines (B and C).

- Maximum on B = 16 minutes
- Maximum on C = 18 minutes

Step 3: Check the condition:

- If the minimum time on A and D is greater than or equal to the maximum time on B and C, then the problem can be reduced to a two-machine problem.
- Since $28 > 16$ and $32 > 18$, the condition is satisfied.

Step 4: Create two imaginary machines:

- Machine P = A + B + C (combined processing time for each job)
- Machine Q = B + C + D

Step 5: Apply Johnson's Rule to the new two-machine problem (P and Q) to determine the optimal job sequence.

- Based on the shortest processing times, the optimal sequence is:
3 → 2 → 1 → 4

Figure 15.3.8 Jobs – Johnson’s Rule

	MACHINES	
Jobs	P (Process Time)	Q (Process Time)
1	$58 + 14 + 14 = 86$	$48 + 14 + 14 = 76$
2	58	60
3	56	72
4	92	70

Performance Evaluation

After sequencing, calculate the waiting times and idle times for each machine. The results are as follows:

Figure 15.3.9 Waiting & Idle Times

	Machines								Idle Time			
Jobs	A		B		C		D		A	B	C	D
	Start	End	Start	End	Start	End	Start	End				
3.	0	28	28	40	40	56	56	100	0	28	40	56
2.	28	58	58	68	68	86	100	132	0	$58 - 40 = 18$	$68 - 56 = 12$	$100 - 100 = 0$
1.	58	116	116	130	130	144	144	192	0	$116 - 68 = 48$	$130 - 86 = 44$	$144 - 132 = 12$
4.	116	180	180	196	196	208	208	250	0	$180 - 130 = 50$	$196 - 144 = 52$	$208 - 192 = 16$

- Total idle time:
 - Machine A: 70 minutes
 - Machine B: 198 minutes

- Machine C: 190 minutes
- Machine D: 84 minutes
- Total flow time (makespan): 250 minutes

This approach demonstrates how a complex multi-machine scheduling problem can be simplified using Johnson's Rule, provided the necessary conditions are met.

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15.4 RESOURCE ASSIGNMENT IN OPERATIONS SCHEDULING

In earlier sections, we explored how jobs are scheduled across multiple machines. However, in some operational settings, resources must be assigned on a one-to-one basis—for example, assigning a specific crane to a construction site or a worker to a particular task. In such cases, the objective is to assign each resource to exactly one job in a way that minimizes total cost or time.

This type of problem is solved using a specialized version of the transportation model known as the **Hungarian Method** (also referred to as the *Kuhn-Munkres Algorithm*). Unlike general transportation problems, the Hungarian Method ensures that each resource is assigned to exactly one job, and each job is assigned to exactly one resource.



Example: Crane Assignment Problem

A construction firm is working on four sites (A, B, C, and D) and has four cranes (1, 2, 3, and 4). The time (in weeks) it takes each crane to complete work at each site is shown in the cost matrix below. The goal is to assign each crane to one site such that the total time of crane usage is minimized.

Figure 15.4.1 Cranes & Sites

Cranes	Construction Sites			
	A	B	C	D
1	14	5	8	7
2	2	12	6	5
3	7	8	3	9
4	2	4	6	10

See the process below to apply the Hungarian Method.

Step 1: Row Reduction

- Identify the minimum value in each row and subtract it from all elements in that row.
- This ensures that each row has at least one zero.

Figure 15.4.2 Cranes & Sites (Step 1)

	Construction Sites			
Cranes	A	B	C	D
1	8	0	2	2
2	0	9	4	3
3	4	4	0	5
4	0	2	5	7

Step 2: Column Reduction

- For each column, subtract the minimum value in that column from all elements.
- This ensures that each column also has at least one zero.

Figure 15.4.3 Cranes & Sites (Step 2)

	Construction Sites			
Cranes	A	B	C	D
1	8	0	2	0
2	0	9	4	1
3	4	4	0	3
4	0	2	5	5

Step 3: Cover All Zeros with Minimum Number of Lines

- Use horizontal lines through Row 1 and vertical lines through Column 1 to cover all zeros in the matrix.
- Vertical line through Column 3
- If the number of lines is less than the matrix dimension ($n = 4$), proceed to adjust the matrix.

Figure 15.4.4 Cranes & Sites (Step 3)

	Construction Sites			
Cranes	A	B	C	D
1	8	0	2	0
2	0	9	4	1
3	4	4	0	3
4	0	2	5	5

Step 4: Matrix Adjustment

- Find the smallest uncovered value (k). $k = 1$ (Row 2, Column 4)
- Subtract k from all uncovered elements.
- Add k to elements at intersections of lines.

Figure 15.4.5 Cranes & Sites (Step 4)

	Construction Sites			
Cranes	A	B	C	D
1	9	0	3	0
2	0	8	4	0
3	4	3	0	2
4	0	1	5	4

- Repeat Steps 3 and 4 until the number of lines equals the matrix dimension.

Step 5: Zero Crossing for Matrix Adjustment / Optimal Assignment

- Select zeros such that no row or column contains more than one assignment.

	Construction Sites			
Cranes	A	B	C	D
1	9	0	3	0
2	0	8	4	0
3	4	3	0	2
4	0	1	5	4

Figure 15.4.6 Cranes & Sites (Step 5)

15.4.6 Image Description

The image (15.4.6) depicts the following table with red lines crossing out columns corresponding to construction sites A, C, and D, as well as row 1.

	Construction Sites			
Cranes	A	B	C	D
1	9	0	3	0
2	0	8	4	0
3	4	3	0	2
4	0	1	5	4

- If multiple zeros exist in a row or column, choose the one that allows for a complete assignment.

Figure 15.4.7

	Construction Sites			
Cranes	A	B	C	D
1		0		0
2	0			0
3			0	
4	0			

To decide which four zeros must be selected, we need to consider that no crane can be assigned to more than

one site. Therefore, if we have only one zero under any site, that zero would be selected. If we have more than one zero, we have to decide which one to assign

Final Assignment and Result

After applying the Hungarian Method, the optimal assignments yield a cost of 140 and as shown below:

- **Crane 1 → Site B**
- **Crane 3 → Site C**
- **Crane 4 → Site A**
- **Crane 2 → Site D**

Crane 2 can be assigned to Site A and Site D. If we assign it to Site A, Crane 4 cannot be assigned to any site. So, Site A, which can take Cranes 2 and 4, would take Crane 4, and Crane 2 would be assigned to Site D, as shown below.

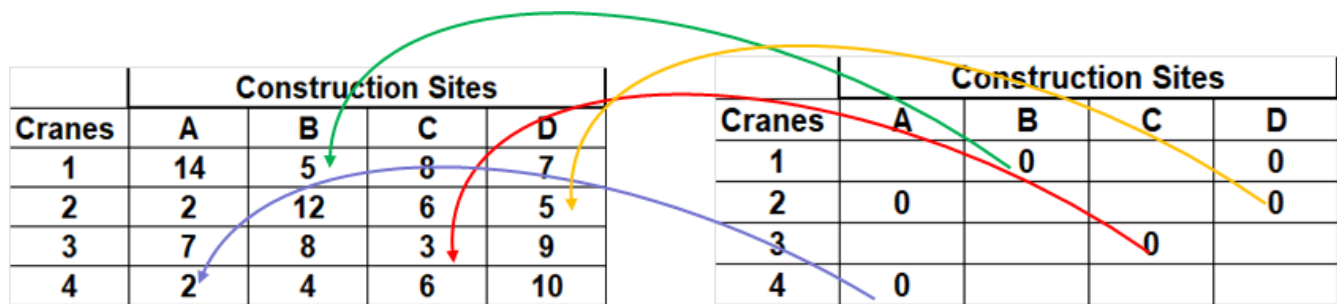


Figure 15.4.8 Final Result

15.4.8 Image Description

The image features two tables connected by coloured arrows, each representing the allocation of cranes to construction sites. Here are the descriptions of the tables and arrows:

Table A

	Construction Sites			
Cranes	A	B	C	D
1	14	5	8	7
2	2	12	6	5
3	7	8	3	9
4	2	4	6	10

Table B

	Construction Sites			
Cranes	A	B	C	D
1		0		0
2	0			0
3			0	
4	0			

Arrows connect values in the first table to the corresponding allocations in the second table:

- A green arrow originates from a 0 value in Table B under crane 1, site B pointing to crane 1, site B, with the value 5 in, Table A.
- A yellow arrow originates from a 0 value in Table B under crane 2, site D pointing to crane 2, site D, with the value 5, in Table A .
- A red arrow originates from a 0 value in Table B under crane 3, site C pointing to crane 3, site C, with the value 3, in Table A.
- A blue arrow originates from a 0 value in Table B under crane 4, site A pointing to crane 4, site A, with the value 4, in Table A.

This assignment yields a minimum total time of 15 weeks, calculated as:

$$\text{Total Time} = 2 (\text{Crane 1}) + 5 (\text{Crane 3}) + 3 (\text{Crane 4}) + 5 (\text{Crane 2}) = \mathbf{15 \text{ weeks}}$$

This example illustrates how the Hungarian Method provides an efficient and systematic approach to solving one-to-one resource assignment problems in operations scheduling.

15.5 SERVICE SHOP SCHEDULING

Unlike manufacturing environments that often rely on special-purpose machines, service shops typically use multi-purpose equipment and face more dynamic scheduling challenges. Jobs in service settings vary in nature, arrive at different times, require different processing durations, and have distinct due dates. These complexities make scheduling in service shops both critical and nuanced.

Key performance considerations in service scheduling include:

- **Flow Time:** Total time required to complete a job from start to finish.
- **Work in Progress (WIP):** Number of jobs currently being processed.
- **Lateness:** The extent to which a job is completed after its due date.

To manage these challenges, service providers must choose appropriate job sequencing strategies. Common strategies include:

First Come, First Served (FCFS)

- Jobs are processed in the order they arrive.
- Widely used in public service settings (e.g., medical clinics, government offices).
- Simple and fair, but may not optimize flow time or minimize lateness.

Shortest Processing Time (SPT)

- Jobs with the shortest processing time are completed first.
- Helps reduce average flow time and WIP.
- May delay longer jobs, increasing their lateness.

Earliest Due Date (EDD)

- Jobs are scheduled based on their due dates, with the earliest due date processed first.
- Minimizes maximum lateness.
- Useful when meeting delivery deadlines is a priority.

Critical Ratio (CR)

- A dynamic priority rule that considers both due date and remaining work.
- Formula:

$$CR = \frac{\text{Remaining Time to Delivery}}{\text{Work Remaining}} = \frac{\text{Due Date-Today's Date}}{\text{Work Time Remaining}}$$

- Jobs with CR 1 are at risk of being late and should be prioritized.
- Balances urgency and workload.

Longest Processing Time (LPT)

- Opposite of SPT: jobs with the longest processing time are completed first.
- Useful when longer jobs risk being delayed due to time constraints later in the schedule.



Example: Jimmy Auto Repair

Jimmy Auto Repair receives five service jobs, each with different processing times and due dates. The processing time and delivery time of these jobs are summarized in the following table.

Figure 15.5.1

Jobs	Process time (hours)	Due time (hours)
A	16	36
B	8	30
C	40	100
D	10	39
E	35	90

The impact of different sequencing strategies is as follows:

FCFS Strategy

- Jobs are processed in arrival order.
- Results in delays for *Jobs D and E*.

Figure 15.5.2 – FCFS Strategy

Jobs	Process time (hours)	Due time (hours)	Flow time	Lateness
A	16	36	16	0
B	8	30	24	0
C	40	100	64	0
D	10	39	74	35
E	35	90	109	19

SPT Strategy

- Jobs with the shortest processing times are completed first.
- Only *Job C* is delayed (by 9 hours).

Figure 15.5.3 – SPT Strategy

Jobs	Process time (hours)	Due time (hours)	Flow time	Lateness
B	8	30	8	0
D	10	39	18	0
A	16	36	34	0
E	35	90	69	0
C	40	100	109	9

EDD Strategy

- Jobs are scheduled by due date.
- Only *Job C* is delayed (by 19 hours).

Figure 15.5.4 – EDD Strategy

Jobs	Process time (hours)	Due time (hours)	Flow time	Lateness
B	8	30	8	0
A	16	36	34	0
D	10	39	44	0
E	35	90	79	0
C	40	100	119	19

CR Strategy

- Jobs are prioritized based on urgency and workload.
- *Jobs E, B, and D* are delayed by 1, 68, and 69 hours, respectively.

Figure 15.5.5 – CR Strategy

Jobs	Process time (hours)	Due time (hours)	Flow time	Lateness	CR
A	16	36	16	0	2.25
C	40	100	56	0	2.5
E	35	90	91	1	2.57
B	8	30	98	68	3.75
D	10	39	108	69	3.9

LPT Strategy

- Longer jobs are processed first.
- Results in delays for *Jobs A, D, and B* (55, 62, and 79 hours, respectively).

Figure 15.5.6 – LPT Strategy

Jobs	Process time (hours)	Due time (hours)	Flow time	Lateness
C	40	100	40	0
E	35	90	75	0
A	16	36	91	55
D	10	39	101	62
B	8	30	109	79

The choice of sequencing strategy has a significant impact on *lateness*, *flow time*, and *workload distribution*. While FCFS is simple and fair, strategies like SPT, EDD, and CR offer more control over performance metrics. In service environments where customer satisfaction and timely delivery are critical, selecting the right scheduling approach can enhance both operational efficiency and service quality.

15.6 CHAPTER SUMMARY & REVIEW



Summary

This chapter examines short-term scheduling in operations management, which involves determining the sequence and timing of jobs to optimize the use of limited resources such as machines, labour, and time. Scheduling is critical in both manufacturing and service industries because it affects efficiency, job flow time, lateness, makespan, and customer satisfaction. In manufacturing, scheduling challenges arise from job variety, machine availability, and operation sequences, which necessitate prioritization rules such as Earliest Due Date (EDD) or Shortest Processing Time (SPT). More complex cases—such as jobs processed across two or more machines—can be solved using techniques like Johnson's Rule, while resource assignment problems (e.g., allocating cranes to sites) can be addressed using the Hungarian Method.

In service settings, scheduling is further complicated by job arrival times, due dates, and varying processing times. Common rules include First-Come, First-Served (FCFS) for fairness, SPT to reduce flow time, EDD to minimize lateness, Critical Ratio (CR) to balance urgency, and Longest Processing Time (LPT) when longer jobs risk delays. The chapter highlights how the choice of rule impacts overall efficiency and performance trade-offs, showing that no single approach is universally best. Ultimately, effective scheduling requires selecting strategies that align with organizational objectives, whether minimizing costs, meeting deadlines, or improving customer service, making it a vital tool for achieving operational excellence.

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Review Questions

1. The Earliest Due Date (EDD) rule selects a job for processing based on its smallest processing time.

a) True b) False

Answer

b) False

2. In the Shortest Processing Time (SPT) rule, jobs are sequenced based on their processing times.

a) True b) False

Answer

a) True

3. Johnson's Rule is used to sequence jobs to be processed on machines arranged in:

a) Sequence b) Parallel

Answer

a) Sequence



Model Questions

- Five teachers are scheduled to teach five different subjects to a first-year management class.
Which priority criterion would be most appropriate for formulating the timetable?
- The following table provides the processing time and due dates for five jobs.
Sequence the jobs using both the Shortest Processing Time (SPT) and Earliest Due Date (EDD) rules.

Job	Processing Time (days)	Due Date (days)
1	6	5
2	7	3
3	4	4
4	9	7
5	5	2

- Seven jobs must be processed through two operations: Machine A, followed by Machine B.
Sequence the jobs using Johnson's Rule based on the following processing times:

Job	Processing Time on A	Processing Time on B
1	9	6
2	8	5
3	7	7
4	6	3
5	1	2
6	2	6
7	4	7

4. Sequence the following three jobs to be processed on three machines in the order:
Machine A → Machine B → Machine C.

Job	Processing Time on A	Processing Time on B	Processing Time on C
1	11	14	6
2	8	10	11
3	9	12	7

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15.7 CHAPTER PROBLEMS



Chapter Problems

1. Define job scheduling. Explain its significance in both manufacturing and service operations.
2. List and describe four common job scheduling rules. Discuss the advantages and disadvantages of each.
3. Consider the following jobs with their processing times and due dates:

Job	Processing Time (Hours)	Due Date (Hours)
A	16	36
B	8	30
C	40	100
D	10	39
E	35	90

4. Apply the following scheduling rules to the jobs in Question 3:
 - First-Come, First-Served (FCFS)
 - Shortest Processing Time (SPT)
 - Earliest Due Date (EDD)

For each rule, calculate:

- Average Flow Time
- Average Lateness

- Maximum Tardiness
5. Based on your calculations in Question 4:
 - Which rule would you recommend to minimize average flow time?
 - Which rule would you recommend to minimize maximum tardiness?
 - Justify your recommendations.
 6. What is the Critical Ratio (CR) rule?
 - Calculate the CR for each job in Question 3.
 - Sequence the jobs using the CR rule.
 - Calculate the average tardiness for this sequence.
 7. Explain the concept of “makespan.”
 - How is it calculated?
 - Why is it an important metric in job scheduling?
 8. A manufacturing company has five jobs to be processed on two machines (Machine 1 and Machine 2). The processing times are as follows:

Job	Machine 1 (Hours)	Machine 2 (Hours)
1	5	6
2	6	8
3	5	6
4	7	4

9. Determine a job sequence that minimizes the makespan for the jobs in Question 8. (Hint: This may require applying Johnson’s Rule or another advanced scheduling technique.)
10. A construction company needs to assign four cranes to four construction sites. The cost matrix for assigning each crane to each site is given below:

Crane	Site A	Site B	Site C	Site D
1	13	5	7	7
2	2	11	6	5
3	7	7	3	8
4	2	4	7	9

11. Use the Hungarian Algorithm (or another appropriate method) to determine the optimal assignment of cranes to sites that minimizes total cost.
12. Discuss the limitations of the scheduling rules presented in this chapter. What real-world factors are often not considered by these rules?
13. How can technology improve job scheduling in practice? Discuss the role of tools such as scheduling software, real-time data, and automation in enhancing scheduling accuracy and responsiveness.

15.8 CASE STUDY: LONDON CUSTOM CAKERY



Case Study: London Custom Cakery

London Custom Cakery is a small, home-based enterprise specializing in custom pies and cakes for special occasions. The business was founded by four graduates of Fanshawe College's Culinary and Hospitality program—Mary, Nancy, Sandra, and Julie. Since its inception two years ago, the cakery has achieved notable success within the local community.

This week, in addition to their regular orders, the team faces a unique challenge: five high-profile wedding cake orders from prominent families in the area. The details of these orders are presented in the table below.

Operational Challenge

The team is currently facing issues with their cooling system, which has prompted a debate among the partners regarding the optimal sequence for processing the wedding cake orders.

- *Mary* advocates for handling the orders in the sequence they were received.
- *Nancy* suggests prioritizing the orders that can be completed most quickly.
- *Sandra* recommends focusing on the orders with the earliest due dates.

Julie, the most experienced in business operations, intervenes with a more analytical approach. She advises: *"Let's stay calm. We have limited space in the kitchen, and wedding cakes require precision and care. Since we have already completed orders*

occupying space, we should consider the average number of wedding jobs in progress to determine which strategy will ensure the smoothest workflow.” Her suggestion is met with agreement, as the others recognize her operational insight.

Logistics and Cost Considerations

Four of the five families—Adamson, Coloney, Dawson, and Edwards—have requested professional transportation and catering services for their cakes. To meet these needs, four caterers have been subcontracted. Their charges vary based on distance, cake size, and serving time. The cost breakdown for each family and caterer is shown below:

Caterer	Adamson	Coloney	Dawson	Edwards
Charlie	\$1300	\$1600	\$1100	\$1800
Gerald	\$1300	\$1500	\$1000	\$1200
Jhonny	\$1500	\$1100	\$2000	\$1500
Rick	\$1700	\$1700	\$1200	\$2200

Questions

As their consultant, you are asked to provide guidance on two key decisions:

1. *Order Processing Strategy*
 - Which partner’s suggestion (Mary’s, Nancy’s, or Sandra’s) should be followed?
 - Justify your recommendation based on operational efficiency and workflow management.
2. *Catering Cost Optimization*
 - Determine the optimal assignment of caterers to families to minimize total catering and delivery costs.
 - Identify which caterer should be assigned to each family.

15.9 KEY TERMS



Key Terms

- **Batch production systems:** produce goods in groups, with different products requiring different operations and setups.
- **Critical Ratio (CR):** a dynamic priority rule that considers both due date and remaining work.
- **Earliest Due Date (EDD):** Jobs are scheduled based on their due dates, with the earliest due date processed first.
- **First Come, First Served (FCFS):** jobs are processed in the order they arrive.
- **Flow Time:** total time required to complete a job from start to finish.
- **Hungarian Method (Kuhn-Munkres Algorithm):** ensures that each resource is assigned to exactly one job, and each job is assigned to exactly one resource.
- **Johnson's Rule:** a scheduling method used to minimize the total makespan (the time required to complete all jobs) when sequencing jobs through two work centers (or machines) in the same order.
- **Lateness:** the extent to which a job is completed after its due date.
- **Longest Processing Time (LPT):** Jobs with the longest processing time are completed first.
- **Mass production systems:** produce large quantities of standardized goods using the same sequence of operations.
- **Makespan:** the total time required to complete a set of jobs from start to finish.
- **Scheduling:** the process of determining the sequence and timing of jobs to be completed within a short-term planning horizon, typically within a day.
- **Shortest Processing Time (SPT):** Jobs with the shortest processing time are

completed first.

- **Work in Progress (WIP):** number of jobs currently being processed.

CHAPTER 16: JUST-IN-TIME AND LEAN SYSTEMS

Chapter Overview

[16.0 Learning Outcomes](#)

[16.1 Just-in-Time and Lean Manufacturing Concepts](#)

[16.2 Lean Manufacturing and Control](#)

[16.3 Core Objectives and Principles of Lean Manufacturing](#)

[16.4 Just-In-Time \(JIT\) Systems](#)

[16.5 Chapter Summary & Review](#)

[16.6 Key Terms](#)

16.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Explain the fundamental principles of Just-In-Time (JIT) and lean manufacturing, identifying how these approaches aim to eliminate waste and improve efficiency in production processes.
- Describe the core objectives and principles of lean manufacturing, including the five core principles identified by James Womack and Daniel Jones, and apply these principles to analyze and improve manufacturing processes.
- Outline the key components and benefits of Just-In-Time (JIT) systems, including inventory reduction, pull production systems, quick setups, and flexible resources, and evaluate how these components contribute to operational efficiency and waste reduction.
- Discuss the commonly observed types of waste (transportation, Excessive inventory, excessive motion, waiting, overproduction, overprocessing, defects).
- Examine the process of Value Stream Mapping, to remove or reduce non-value adding activities through Kaizen and convert a push production system to a pull system using Kanban and supermarket.

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16.1 JUST-IN-TIME AND LEAN MANUFACTURING CONCEPTS



Imagine ordering a pizza for dinner from a restaurant that advertises a delivery time of six hours. Clearly, such a prolonged wait would be unacceptable, as the pizza would arrive cold and stale, failing to meet the customer's expectations. Conversely, a restaurant that promises to deliver a cold, stale pizza within five minutes would also be unsatisfactory. To truly satisfy consumer needs, a pizza shop must be capable of providing customers with the desired number of fresh pizzas at the precise time they are wanted.

Preparing pizzas in advance would be wasteful, as most consumers are unlikely to purchase a stale product. Conversely, an excessively long delivery time would result in the loss of customers to more responsive competitors. The concept of **just-in-time (JIT)** focuses on producing goods or services to meet customer demand only when they are needed. For a pizza delivery shop, this translates to delivering a fresh pizza to the customer's doorstep within approximately 30 minutes.

This philosophy can be applied to a wide range of operations, from simple tasks like washing a car to the complex manufacturing of aircraft. Similarly, the concept of **lean manufacturing** refers to the elimination of waste in the manufacturing process. The Toyota Production System serves as a model for modern manufacturers seeking to control and minimize waste.

The core focus of Lean system is to tackle waste. By definition, any activity in a process that does not have any value for the customer is waste. As a result, the customer will not pay for these activities, yet resources have been allocated to those activities at a cost. In this unit, we will explore seven types of waste as shown in the following video and later we will look at the processes for controlling them.

Video: “[7 wastes in garments factory | Live form Factory](#)” by [Garments Learner](#) [3:56]
is licensed under the [Standard YouTube License](#).

Additionally, we will delve into the origins of the Just-in-Time (JIT) philosophy and the use of pull systems to control inventory effectively. By embracing the principles of just-in-time and lean manufacturing, organizations can streamline their operations, minimize waste, and enhance their ability to meet customer demands promptly and efficiently, ultimately improving customer satisfaction and operational performance.

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“[Pizza Deliver icon](#)” by [Us and Up](#), [Flaticon License](#)

16.2 LEAN MANUFACTURING AND CONTROL

Lean control, or simply lean, has seen a surge in popularity in recent years as businesses strive to improve operational efficiencies and product quality through lean methodologies. **Lean control** is a refined example of nonfinancial controls in action aimed at enhancing product and service quality while reducing waste. Originally focused on improving manufacturing operations, lean concepts have now expanded to encompass product development, order processing, and various other non-manufacturing processes, sometimes referred to as “lean in the office.”

The widespread adoption of lean control methodologies is driven by the quest for streamlining processes, eliminating waste, and maximizing productivity. Lean control techniques involve analyzing processes, identifying value-adding activities, and eliminating non-value-adding activities or waste. This process is called Value Stream Mapping (VSM) and is done in three steps:

1. Drawing the current state map (how the operation is currently carried out in an attempt to identify the non-value adding activities (waste) that need to be improved or eliminated).
2. Coming up with ideas of how the non-value-added activities can be improved or eliminated (Kaizen), to outline the future plan (how the operation should be carried out without waste or with less waste, hence with more value-adding activities).

Kaizen is an incremental improvement in a process that might be small, but contributes to continuous improvement.

3. Prepare the future plan (how the operation should be carried out without waste or with less waste (hence with more value-adding activities))

This approach is based on the premise that by eliminating waste, whether in the form of excess inventory, overproduction, waiting times, or unnecessary transportation, businesses can enhance their operational efficiencies and product quality. Value Stream Mapping will be further illustrated in detail in a video in [section 9.4](#), where we learn about the Pull Production System.

Lean control is a multifaceted approach to process improvement and resource optimization. According to James Womack, it involves measuring and reducing inventory, streamlining production, changing performance measurement, and implementing a knowledge-based continuous improvement system. Lean control requires long-term commitment and top management support.

The term “lean” gained popularity after the 1990 book *The Machine That Changed the World* by Womack, Jones, and Roos. The core principle is using fewer resources like space, inventory, and labour while maintaining or improving output levels. This is achieved by identifying and eliminating non-value-adding activities and waste from processes to increase productivity and quality and reduce costs, ultimately enhancing competitiveness (Womack et al., 1990).

Toyota's Pioneering Role in Lean Manufacturing

Video: “[How Toyota Changed The Way We Make Things](#)” by [Bloomberg Originals](#) [4:52] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

The Toyota Production System (TPS), developed by Toyota Motor Corporation in Japan after World War II, serves as the cornerstone of lean manufacturing principles. This period presented significant challenges for Toyota’s leadership, who aspired to establish the company as a full-fledged car and truck manufacturer. The nascent Japanese automotive market, characterized by a demand for diverse vehicle types despite its small size, necessitated a production strategy that balanced profitability with low-volume, high-variety output. Capital scarcity further compounded these challenges, precluding investments in advanced production equipment. To ensure survival and success, Toyota required a resource-efficient vehicle production system. This critical need led Eiji Toyoda and Taiichi Ohno to spearhead the development and implementation of the now-renowned lean production techniques and tools.

To maximize the benefits of lean, managers must determine which specific lean tools and techniques will be effective for their business. This requires a clear understanding of Lean’s primary objectives and core principles. With this understanding, managers can decide which lean tools will work well, which need adaptation, and which are inappropriate.

By aligning lean implementation with lean’s objectives and principles, managers can strategically select and tailor the right lean tools for their business. This targeted approach ensures lean initiatives are tailored to their unique needs, maximizing successful implementation and desired outcomes like improved efficiency, reduced waste, and enhanced quality and productivity. Discerning the suitability of various lean tools is crucial for managers to integrate lean principles and derive maximum benefits effectively.

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16.3 CORE OBJECTIVES AND PRINCIPLES OF LEAN MANUFACTURING

To fully understand and effectively implement lean methodologies, it is crucial to grasp the major objectives and core principles that underpin the lean philosophy.

7 – Wastes

Despite ongoing debates and arguments surrounding the precise definition and description of lean, it is clear that the ultimate objective of lean is to avoid muda, or wasteful activity, in all business operations. Muda comprises seven deadly wastes, and in the lean world, waste is defined as any activity or condition that consumes resources but creates no value for customers. These seven deadly wastes include:



DEFECTS



OVER PRODUCTION



TRANSPORTATION



WAITING



INVENTORY



MOTION



OVER - PROCESSING

“7 Deadly Wastes” by Koen Liddiard, [CC BY-NC-SA](https://creativecommons.org/licenses/by-nc-sa/4.0/)

1. **Defects:** Products that fail to meet customer requirements, rendering the effort to create them wasted and necessitating additional waste management processes.
2. **Overproduction:** Producing or acquiring items before they are actually required, leading to excess inventory that must be stored, managed, and protected, often masking underlying production problems.
3. **Transportation:** Moving products without adding value, incurring costs, and risking damage, loss, or delays.
4. **Waiting:** Idle time spent by workers or capital tied up in goods and services not yet delivered to customers, often requiring additional processes to manage.
5. **Inventory:** Raw materials, work-in-progress, or finished goods representing capital outlay that has not yet generated income, with any non-value-adding inventory considered waste.
6. **Motion:** Unnecessary movements by workers or equipment that can lead to damage, wear, and safety issues, as well as incur fixed assets and expenses.
7. **Over-processing:** Using more expensive or valuable resources than necessary or adding features that are unneeded by customers, potentially leading to waste, particularly in terms of overqualified personnel performing tasks below their competency level.

By identifying and eliminating these seven deadly wastes, lean methodologies aim to streamline operations, reduce costs, and enhance value creation for customers, ultimately driving business success and competitiveness.

Video: “[The 7 Wastes of Lean for Frontline Kaizen – Lean Manufacturing Training](#)” by [Lean Smarts](#) [6:05] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

The Five Core Principles of Lean

Lean methodologies enable organizations to achieve more with fewer resources. A lean organization utilizes less human effort, equipment, facility space, time, and capital while continually striving to meet customers' exact needs. Lean is not merely a cost-cutting program; it is a philosophy centred on conserving valuable resources.

In their seminal book, *Lean Thinking*, James Womack and Daniel Jones identified five core principles that underpin the lean approach:

Define Value from the Customer's Perspective

The first principle emphasizes that value must be defined and specified from the customer's perspective. This requires a deep understanding of how each specific product or service meets the needs of specific customers at a specific price and time. Generic statements are insufficient; value must be defined in terms of tangible products or services.

Describe the Value Stream for Each Product or Service

The second principle involves describing the value stream for each product or service (or groups of similar products). The value stream encompasses all activities, both direct and indirect, performed to bring a finished product or service to the customer. This includes manufacturing activities, order processing, purchasing, and materials management. Mapping the value stream reveals waste, enabling managers to identify value-adding activities, non-value-adding but necessary activities, and non-value-adding activities that can be eliminated or reduced.

Create Flow in Each Value Stream

The third principle is embodied in the concept of flow. Once non-value-adding activities have been eliminated, the remaining activities should be arranged sequentially to enable smooth and continuous product or service flow. Flow challenges the traditional "batch-and-queue" model, where products are manufactured in large batches based on functional organization. Lean organizations strive to improve flow by reducing batch sizes, increasing flexibility, and lowering costs.

Video: “[Lean Manufacturing One Piece Flow vs. Mass Production Paper Airplane Simulation \(Lean Tip 005\)](#)” by [Lean Smarts](#) [7:46] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Produce at the Pace (Pull) of Actual Customer Demand

The fourth principle is producing at the pace or pull of actual customer demand. Continuous flow production dramatically reduces lead times, enabling lean organizations to respond to actual customer demand rather than relying on demand forecasts. This allows for substantial reductions in finished goods and work-in-process inventories.

Strive for Continuous Improvement (Kaizen)

The fifth principle is continuous improvement, expressed in Japanese as “kaizen.” Lean organizations adopt the mindset that any business activity can be improved and regularly conduct kaizen events to enhance specific processes or operations. Even the leanest organizations, like Toyota, continuously strive for improvement, recognizing that pursuing perfection is an ongoing journey.

By adhering to these five core principles, organizations can effectively implement lean methodologies, eliminate waste, enhance value creation for customers, and drive continuous improvement, ultimately achieving operational excellence and sustainable competitive advantage.

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16.4 JUST-IN-TIME (JIT) SYSTEMS

Just-In-Time (JIT) is a management philosophy that emerged in the 1970s, pioneered by Taiichi Ohno and perfected for Toyota's manufacturing plants in Japan. The primary objective of JIT is to eliminate any activity that does not add value from the customer's perspective. Activities that do not contribute value are referred to as "waste" within the JIT framework.

The JIT philosophy aims to eliminate these forms of waste by producing only what is needed when it is needed and in the exact quantity required. This approach minimizes inventory levels, reduces lead times, and enhances overall operational efficiency.

By adopting JIT principles, organizations can streamline their processes, reduce waste, and improve responsiveness to customer demand. JIT systems emphasize continuous improvement, flexibility, and the involvement of all employees in identifying and eliminating non-value-added activities.

Successful implementation of JIT requires a cultural shift within the organization, fostering a mindset of continuous improvement, waste elimination, and a relentless pursuit of perfection in meeting customer needs. By embracing the JIT philosophy, companies can achieve significant improvements in quality, productivity, and competitiveness, ultimately driving long-term business success.

Three essential elements 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

Excess inventory can mask wasteful practices like poor equipment, weak vendors, bad quality, and long setup times. Gradually reducing inventory exposes these weaknesses, allowing organizations to address them systematically.

As inventory levels decrease, organizations can replace or maintain equipment, improve vendor quality and delivery, streamline setups, implement robust quality practices, and optimize labour/equipment layout.

Inventory reduction exposes waste, creates urgency for improvement, and fosters a continuous improvement mindset. Organizations can streamline processes, enhance efficiency, reduce costs, improve responsiveness, and deliver greater customer value by using it as a tool to identify and eliminate non-value-added activities.

Pull Production System

Traditional manufacturing management approaches emphasize maximizing machine and labour utilization, assuming that keeping workers and machines constantly busy will lead to productivity and efficiency. This approach is known as the **“push” system**, where raw materials and work-in-process are continuously pushed through the factory in pursuit of high utilization. However, this method often results in high inventory levels, long lead times, overtime costs, increased rework potential, and a competitive rather than cooperative workforce.

In contrast, Just-In-Time (JIT) employs a “pull” system, where workflows to a work centre only when that centre needs more work. If a work centre is already occupied, the upstream work centre should stop production until the downstream centre communicates a need for more material. The emphasis on maintaining high utilization is removed in a JIT environment. Instead, the focus shifts to addressing challenges that affect the factory’s overall effectiveness in meeting its strategic goals, such as setup time

reduction, quality improvement, enhanced production techniques, and waste elimination, rather than allowing excess inventory to cover up inefficiencies that reduce competitiveness.

Video: “[[Toyota Production System](#)] Just-in-Time: The Pull System” by [Toyota Motor Corporation](#) [1:14] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

One of the tools used in JIT systems to facilitate the **pull system** and coordinate activities (such as picking up new raw materials, work-in-process, or production itself) between different workstations is called **Kanban**. Kanban is a signal or ticket that is passed from one part of the process to another, indicating that they are allowed to start their next activity. This supports the concept of pull production and avoids waste by preventing activities from occurring when they are not needed. Kanban is also a visual signboard used to organize and display what needs to be done, what is in progress, and what is completed, a concept adopted in Agile workflow management systems.



In [section 9.2](#) we learned that **Value Stream Mapping** is a process used for eliminating waste, and the most costly waste, inventory. Value stream mapping intends to turn a push production system into a pull system. Two key tools used in this process are Kanban, and Supermarket.

By implementing a demand-pull production system and leveraging tools like Kanban, organizations can streamline their operations, reduce waste, and enhance responsiveness to customer demand, ultimately improving overall efficiency and competitiveness.

Watch the following videos to get a better sense of how the Kanban system works:

Video: “[[Toyota Production System](#)] Just-in-Time: Collaboration with Parts Suppliers for Timely Production” by [Toyota Motor Corporation](#) [2:09] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Video: “[[What is Kanban? – Agile Coach \(2019\)](#)]” by [Atlassian](#) [5:32] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

In [section 9.2](#) we learned that Value Stream Mapping (VSM) is a process used for eliminating waste, and the costliest waste, inventory. Value stream mapping intends to turn a push production system into a pull system. Two key tools used in this process are Kanban, and Supermarket. Watch the following video to gain a better insight into how VSM uses these two tools to transition a traditional push production into a pull production system.

Video: “[[VSM .Value Stream Mapping](#)]” by Shrinivas Gondhalekar [8:35] is licensed under the [Standard YouTube License](#). [Transcript](#).

Quick Setups to Reduce Lot Sizes

Traditional production management philosophies promoted the notion that long production runs of the same item were key to driving down unit costs. However, the problem with this approach was that large production runs created excessive quantities of work-in-process (WIP) and finished goods inventory, far exceeding actual demand. Consequently, these excess inventories led to high inventory costs, long lead times, increased potential for rework, and low flexibility in responding to customer needs.

In a Just-In-Time (JIT) environment, reducing setup costs and setup times is crucial for dramatically improving factory competitiveness. In the 1980s, 3M transformed a factory that produced a few adhesive products in long production runs into a facility that manufactured over 500 adhesive products in small

production runs. To maintain low unit production costs, 3M focused on optimizing the setups on its coating machines.

Since the cost of chemical waste disposal was a significant factor in the cost of changing over a coating machine to produce another product, 3M took several steps to shorten setup times:

1. Reducing the length of hoses that needed purging
2. Redesigning the shape of the adhesive solution holding pan on the coating machine to be shallower
3. Implementing quick-connect devices and disposable filters
4. Utilizing work teams to speed up setups

As a result of these efforts, 3M could maintain low unit costs on its coating machines while producing small lots of hundreds of products to meet market demand quickly and efficiently.

By embracing quick setup practices and reducing lot sizes, organizations can minimize excess inventory, shorten lead times, increase flexibility in responding to customer needs, and ultimately enhance their competitiveness in the market. Quick setups enable companies to produce the right products in the right quantities at the right time, aligning with the core principles of the Just-In-Time philosophy.

Flexible Resources

The enemy of Just-In-Time (JIT) is uncertainty. A JIT environment thrives on predictability in customer demand, production processes, supplier performance, and worker availability. However, complete elimination of uncertainty is often unrealistic in most organizational environments.

To defend against unavoidable uncertainty, implementing Flexible Resources that can adapt easily to changing circumstances is crucial. One way to improve flexibility is through the use of general-purpose, movable equipment that can fulfill a wide variety of production requirements. For example, drilling machines with quick-change bits that 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, enabling any car to be painted any colour without the need to purge hoses when switching from one colour 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 a single machine and working independently, multifunctional workers have a “big picture” view of the production line, understanding all aspects of the line and how to work together to meet quality and schedule goals regardless of the circumstances.

By implementing flexible resources, such as general-purpose equipment and multifunctional workers, organizations can better adapt to changing circumstances and mitigate the impact of uncertainty. This flexibility enables them to respond quickly to fluctuations in demand, production disruptions, or other unforeseen events, ensuring that they can continue to meet customer needs efficiently and effectively within the JIT.

Cellular Flow Layouts

Cellular flow layouts promote JIT goals through unidirectional product flows, high visibility, and fast throughput times. Multifunctional workers are assigned to cells and have responsibility over products from raw materials to finished goods.

This “big picture” view gives workers greater ownership and pride. Their deeper process understanding increases opportunities to contribute ideas for improvement.

Key benefits of cellular layouts for JIT:

- Streamlined flow, minimizing transportation.
- High visibility aids issue identification.
- Reduced lead times and faster throughput.
- Flexibility from cross-trained workers.
- Continuous improvement from engaged workers.

Cellular layouts create an environment supporting JIT principles like waste reduction, lead time reduction, and continuous improvement while empowering workers.

Total Quality Management

Total Quality Management (TQM) goes hand in hand with the Just-In-Time (JIT) philosophy. Poor quality is a major source of uncertainty and non-value-added activities that disrupt JIT flow.

TQM promotes continuous improvement, doing things right the first time, designing quality into products/processes, and focusing on prevention – aligning with JIT’s waste elimination goals.

Key synergies between TQM and JIT:

- Continuous improvement mindset.
- Waste reduction through defect prevention.
- Process optimization for smooth flow.
- Employee empowerment and involvement.
- Customer-centric focus on quality.

Integrating TQM principles into JIT environments mitigates quality-related disruptions, enabling more efficient JIT implementation. This synergistic approach enhances operational excellence and drives continuous improvement.

Employee Empowerment

Front-line employees play a pivotal role in the successful implementation of Just-In-Time (JIT) practices. They work in partnership with management and each other to continuously pursue excellence. Front-line employees contribute to JIT success in several ways:

1. *Problem-solving teams:* Employees work together in teams to gather data and build consensus on improving work processes, fostering a collaborative approach to continuous improvement.
2. *Quality responsibility:* 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, promoting accountability and customer focus.
3. *Empowerment to take action:* Each employee is empowered to take action to correct problems, enabling

swift resolution of issues and minimizing disruptions to the flow of operations.

4. *Cross-functional skill sets*: Employees possess cross-functional skill sets that allow them to be assigned to areas that need support, helping them adopt a broader (“big picture”) view of the production process.
5. *Interconnectedness through demand-pull*: Unlike traditional “push” environments where line workers operate independently, JIT employees are connected by the “demand-pull” discipline, where work is produced only when the downstream work centre needs it, promoting interconnectedness and collaboration.
6. *Basic maintenance responsibilities*: Front-line employees are responsible for the basic maintenance of their machines, fostering a better understanding of equipment conditions and their ability to meet quality and production requirements.
7. *Coaching and facilitation*: Management works with employees as coaches and facilitators rather than authoritative supervisors, creating an environment that encourages proactive teamwork and continuous improvement.

By empowering front-line employees and fostering a culture of collaboration, accountability, and continuous improvement, organizations can harness the full potential of their workforce in support of JIT principles. This approach not only enhances operational efficiency but also promotes employee engagement and ownership, driving sustained success in a JIT environment.

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16.5 CHAPTER SUMMARY & REVIEW



Summary

Chapter 9, “Just-In-Time and Lean Systems,” provides a comprehensive overview of the key principles and practices that underpin these methodologies. The chapter begins by explaining the concepts of JIT and lean manufacturing, which focus on producing goods or services to meet customer demand precisely when needed, thereby eliminating waste and enhancing efficiency. The Toyota Production System is highlighted as a pioneering model in lean manufacturing, showcasing how it transformed production processes to minimize waste and optimize resource use. Lean manufacturing aims to eliminate seven types of waste: defects, overproduction, transportation, waiting, inventory, motion, and over-processing.

The chapter further delves into the core principles of lean manufacturing, which include defining value from the customer’s perspective, mapping the value stream, creating flow, producing at the pace of actual customer demand, and striving for continuous improvement (Kaizen). These principles guide organizations in identifying and eliminating non-value-adding activities, thereby improving overall efficiency and customer satisfaction. The importance of lean control methodologies is also emphasized, highlighting how businesses can enhance operational efficiencies and product quality through systematic waste elimination and process optimization.

Additionally, the document discusses JIT systems, which aim to reduce inventory levels and lead times by producing only what is needed when it is needed. Key elements of JIT include inventory reduction to expose waste, pull production systems facilitated by tools like Kanban, quick setups to reduce lot sizes, flexible resources, and cellular flow layouts. The integration of Total Quality Management (TQM) with JIT is also explored,

emphasizing continuous improvement and employee empowerment as crucial factors in successful JIT implementation. By adopting these principles, organizations can achieve significant improvements in quality, productivity, and competitiveness.

OpenAI. (2024, June 21). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than three paragraphs. Reviewed by authors.*



Review Questions

1. What is the core philosophy behind Just-In-Time (JIT) manufacturing, and how does it differ from traditional manufacturing approaches?
2. Explain the significance of the Toyota Production System (TPS) in the development of lean manufacturing principles.
3. Identify and explain the seven types of waste (muda) targeted by lean manufacturing.
4. What are the five core principles of lean as identified by James Womack and Daniel Jones in their book “Lean Thinking”?
5. Describe the role of a pull production system in JIT and how it contrasts with a push production system.
6. How does Total Quality Management (TQM) integrate with JIT principles to enhance operational efficiency?
7. Explain the concept of cellular flow layouts and their benefits in promoting JIT goals.
8. Discuss the importance of flexible resources in a JIT environment.
9. What steps did 3M take to optimize setups on its coating machines, and how did these steps align with JIT principles?
10. In what ways can empowering front-line employees contribute to the success of JIT practices?

OpenAI. (2024, June 21). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create ten discussion questions based on the attached chapter document that assesses the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

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16.6 KEY TERMS



Key Terms

- **Just-in-time (JIT)** focuses on producing goods or services to meet customer demand only when they are needed.
 - **Kaizen:** an incremental improvement in a process that might be small, but contributes to continuous improvement.
 - **Kanban:** a tool used in different forms (card, bin, etc.) that prompts the flow of work at the time it is needed to increase efficiency and reduce work in progress.
 - **Lean control** is a refined example of nonfinancial controls in action aimed at enhancing product and service quality while reducing waste.
 - **Lean manufacturing** refers to the elimination of waste in the manufacturing process.
 - **Push System: A** Traditional manufacturing system that emphasizes maximizing machine and labour utilization, assuming that keeping workers and machines constantly busy will lead to productivity and efficiency.
 - **Pull System:** a production system where work flows to a work centre only when that centre needs more work (Just-In-Time).
 - **Value Stream Mapping (VSM):** the process of analyzing processes, identifying value-adding activities, and eliminating non-value-adding activities or waste in order to increase productivity.
 - **Waste:** any activity that does not add value for the customer, but is associated with the use of resources at a cost.
-

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CHAPTER 17: RELIABILITY AND MAINTENANCE

Chapter Overview

[17.0 Learning Outcomes](#)

[17.1 Concept and Definition of Reliability](#)

[17.2 Reliability Metrics](#)

[17.3 Maintenance](#)

[17.4 Maintenance Strategies](#)

[17.5 Cost of Reliability and Maintenance](#)

[17.6 Chapter Summary & Review](#)

[17.7 Case Study: Holiday Baskets](#)

[17.8 Key Terms](#)

17.0 LEARNING OUTCOMES



Learning Outcomes

At the end of this chapter, students will be able to:

- Define reliability and maintenance in the context of operations management and explain their importance to organizational performance.
- Calculate system reliability using formulas for both series and parallel configurations, and interpret the implications of adding redundancy.
- Differentiate between key maintenance strategies: reactive, preventive, predictive, condition-based, reliability-centred, and risk-based maintenance.
- Assess the advantages and disadvantages of different maintenance strategies for a variety of assets.
- Analyze the cost implications (direct and opportunity) of various maintenance policies and their impact on operations.
- Apply historical breakdown data to estimate expected costs and advise on optimal maintenance strategies.
- Evaluate opportunity costs related to downtime and their effect on decision-making for maintenance investment.
- Solve practical problems involving maintenance scheduling and reliability calculations.

17.1 CONCEPT AND DEFINITION OF RELIABILITY



As discussed in [Chapter 4](#), reliability and consistent performance are critical considerations in the design of new products. Whether a product is repairable (e.g., a stove) or non-repairable (e.g., a light bulb), its total life cycle cost and acquisition cost are significantly influenced by how long it operates without failure, in other words, by its reliability.

Even in service-oriented businesses, operational success depends heavily on the performance of machinery, equipment, and other physical assets. The uninterrupted functioning of these assets is essential, and this can only be ensured through effective maintenance practices.

Reliability and maintenance are, therefore, foundational elements of operations management, directly impacting a firm's efficiency, service quality, and return on investment. This chapter explores these concepts in detail, supported by numerical examples and practical applications that illustrate their relevance in real-world operational contexts.

Reliability refers to the probability that a machine, product, or system will perform its intended function without failure over a specified period under stated operating conditions. The emphasis on “specified time” is crucial. It reflects the idea of quality sustained over time. In practical terms, when we design, produce, or use products, we expect them to maintain a consistent level of performance throughout their expected lifespan.

Reliability is not limited to individual components; it extends to entire systems. A **system** typically comprises multiple subsystems, each made up of individual components. The overall reliability of a system depends on the reliability of its constituent parts. In many cases, especially when components are arranged in series, the system's reliability is the product of the reliabilities of its components. This interdependence highlights the importance of designing and maintaining each part to ensure the system functions as intended.

Reliability is a key performance metric in both manufacturing and service operations, influencing product quality, customer satisfaction, and operational efficiency.

System Reliability

In operations management and engineering design, **system reliability** refers to the likelihood that an entire system will function without failure over a specified period. For a system composed of n components arranged in series, the system reliability is calculated as the product of the reliabilities of each individual component:

$$R_s = R_1 \times R_2 \times \dots \times R_n$$



Example

Consider a system with four components arranged in series, where:

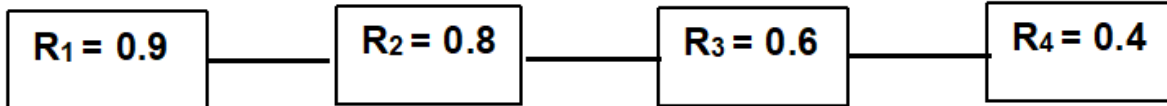


Figure 17.1.1 System Reliability

Where $R_1 = 0.9$, $R_2 = 0.8$, $R_3 = 0.6$, $R_4 = 0.4$

The system reliability is: $R_5 = 0.9 \times 0.8 \times 0.6 \times 0.4 = 0.1728$

This means the system has a 17.28% chance of functioning without failure over the specified time period.

It is important to note that although each individual component has a relatively high reliability, the overall system reliability is significantly lower. This is because in a series configuration, the system fails if any one component fails. As more components are added in series, the probability of system failure increases, resulting in a decline in overall reliability.

Figure 17.1.2 illustrates how system reliability decreases as the number of components in series increases.

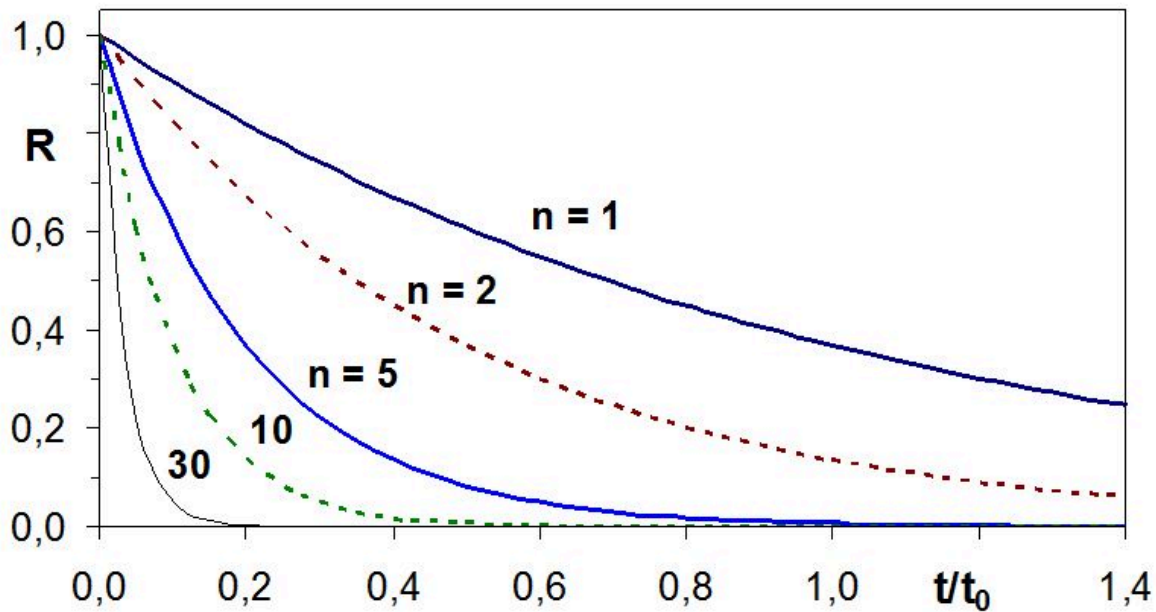


Figure 17.1.2 Parallel system. Time course of reliability for various numbers of elements, n .

17.1.2 Image Description

A line graph shows the reliability function R (vertical axis, ranging from 0 to 1) versus normalized time t/t_0 (horizontal axis, ranging from 0.0 to 1.4). Multiple curves are plotted for different values of n . The curve for $n=1$ (blue solid line) decreases steadily and more slowly compared to the others. The curve for $n=2$ (red dashed line) declines faster than $n=1$. The $n=5$ curve (blue solid line) drops more steeply. The curves for $n=10$ (green dashed line) and $n=30$ (thin black line) decline sharply near the beginning and approach zero quickly. Labels “ $n = 1$,” “ $n = 2$,” “ $n = 5$,” “10,” and “30” are placed near their respective curves. The graph illustrates that reliability decreases faster with increasing values of n .

To counteract this decline, designers often introduce **redundancy**, meaning additional

components or backup systems that can take over in case of failure. Redundancy can significantly improve system reliability, especially in critical applications.

Redundancy in System Reliability

Redundancy refers to the inclusion of additional or backup components in a system to enhance its overall reliability. In a redundant system, components are arranged in parallel, meaning the system continues to function as long as at least one of the parallel components is operational. The system only fails when all redundant components fail.

Redundancy can involve one or more backup units. For example, an n -unit parallel system includes multiple components operating in parallel, any of which can sustain the system's functionality.

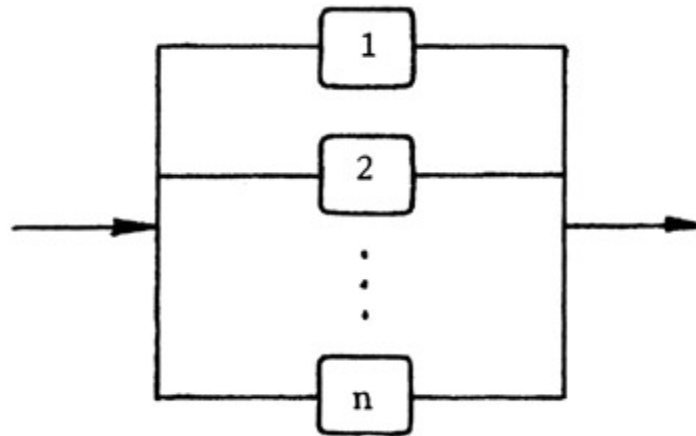


Figure 17.1.3 The reliability block diagram of a reliability-wise parallel system (Kececioglu, n.d.).

17.1.3 Image Description

A schematic diagram showing a parallel system with $\diamond$ components. Each component, labelled 1, 2, ..., n , is represented by a rectangular block connected between two horizontal lines. The left arrow indicates system input, and the right arrow indicates system output. The diagram illustrates that the system continues to operate as long as at least one component functions, representing a parallel reliability configuration.

The reliability of such systems is often calculated using the complement of unreliability, expressed as:

$$R_{sys}(t) = 1 - \prod_{i=1}^n (1 - R_i(t))$$

Figure 17.1.4 (Kececioglu, n.d.).

Where:

- R_{sys} is the system reliability,
- $R(t)$ is the reliability of a single component over time t ,
- n is the number of parallel components.

This formula is derived using the Cumulative Distribution Function (CDF), which represents the probability of failure up to a given point in time.



Example: Two-Unit Parallel System

Consider a system with two identical pumps, each with a reliability of 0.7. The system will function as long as at least one pump is operational. The reliability of the system is calculated as:

$$R_s = R_1 + (R_2)(1 - R_1)$$

Illustrating the above formula in more detail,

R_s	=	R_1	+	(R_2)	$(1 - R_1)$
		The probability that Pump 1 functions without failing		The probability that the second pump functions without failure	The probability that the second pump needs to come to service

Figure 17.1.5 Formula Illustrated.

R_1 : The probability that Pump 1 functions without failing.

R_2 : The probability that the second pump functions without failure.

$(1 - R_1)$: The probability that the second pump needs to come into service.

The formula represents how the total system reliability R_s depends on the reliability of each pump in a parallel configuration.

$$R_s = R_1 + (R_2)(1 - R_1)$$

$$R_s = 0.7 + 0.7(1 - 0.7) = 0.7 + 0.21 = 0.91$$

Thus, the dual-pump system has a 91% chance of operating without failure, significantly higher than the reliability of a single pump.



Example: Redundancy in a Four-Component System

Let's revisit the earlier four-component series system:

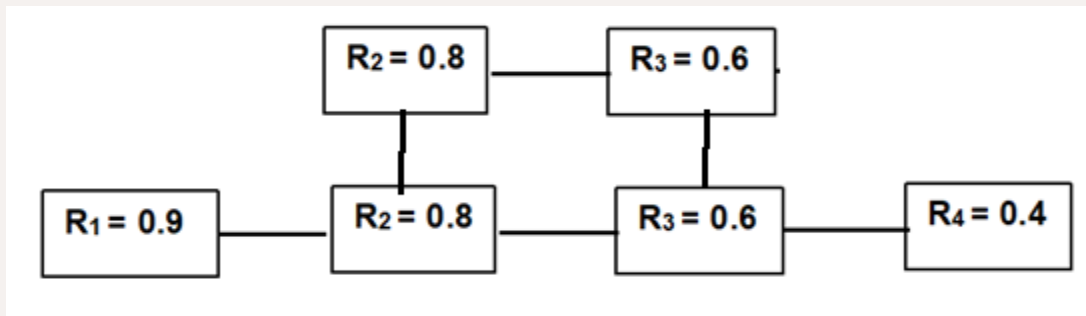


Figure 17.1.6 Four-component series system

Without redundancy, the system reliability was:

$$R_s = 0.9 \times 0.8 \times 0.6 \times 0.4 = 0.1728 \text{ or } 17.28\%$$

Now, suppose **R²** and **R³** are each backed up by identical components (i.e., parallel redundancy). The new system reliability becomes:

$$R_s = R_1 \times [R_2 + R_2 (1-R_2)] \times [R_3 + R_3 (1-R_3)] \times R_4$$

Substituting the values:

$$R_s = 0.9 \times [0.8 + 0.8 (1-0.8)] \times [0.6 + 0.6 (1-0.6)] \times 0.4 = 0.9 \times 0.96 \times 0.84 \times 0.4 = 0.2903 \text{ or } 29.03\%$$

This demonstrates a significant improvement in system reliability—from 17.28% to 29.03%—achieved by introducing redundancy in just two components (Schenkelberg, n.d.).

Interdependence in System Reliability

Interdependence refers to the relationships and dependencies among components or subsystems within a larger system. In interdependent systems, the failure of one component can trigger cascading failures in others, increasing the system's vulnerability. This phenomenon is particularly evident in complex systems such as weather models, financial markets, or power grids, where changes follow stochastic patterns and are often modelled using advanced tools like Markov Chains. While such modelling is beyond the scope of this textbook, the concept of interdependence remains central to understanding system reliability.

Incorporating redundancy into interdependent networks can mitigate the impact of cascading failures by providing alternative pathways or backup components, thereby enhancing overall system resilience.

In less complex systems, interdependence can be analyzed by examining how failures propagate through a process chain, affecting the final yield or performance. The following scenarios illustrate how interdependence influences reliability and how recovery mechanisms can improve outcomes.

Scenario 1: Interdependent Production Stages

Consider a production line with two consecutive stages:

- Stage 1 Reliability: 90%
- Stage 2 Reliability: 90% (if operating independently)

However, if Stage 1 fails, Stage 2 has only a 40% chance of success due to its dependency on Stage 1's output.

Independent Case (No Interdependence)

- $R_{sind} = 0.9 \times 0.9 = 0.81$

Interdependent Case

Let's break down the probabilities:

- Both stages succeed:
 $0.9 \times 0.9 = 0.81$
- Stage 1 succeeds, Stage 2 fails:
 $0.9 \times 0.1 = 0.09$
- Stage 1 fails, Stage 2 succeeds (via rework):
 $0.1 \times 0.4 = 0.04$
- Both stages fail:
 $0.1 \times 0.6 = 0.06$

Total System Reliability (Interdependent)

$$R_s = 0.81 + 0.04 = 0.85$$

This example shows that recovery mechanisms, such as rework or redundancy, can improve reliability even in interdependent systems. However, interdependence generally introduces complexity and potential fragility compared to fully independent systems.

Scenario 2: Wastewater Treatment Filter

In a wastewater treatment plant, a specialized filter is used to remove pathogens during peak flow hours. The system has the following characteristics:

- Initial success rate: 90%
- Usability after peak flow: 80%
- Retrofit success rate: 50% of usable filters
- Fallback success rate: 33% of non-retrofitted filters

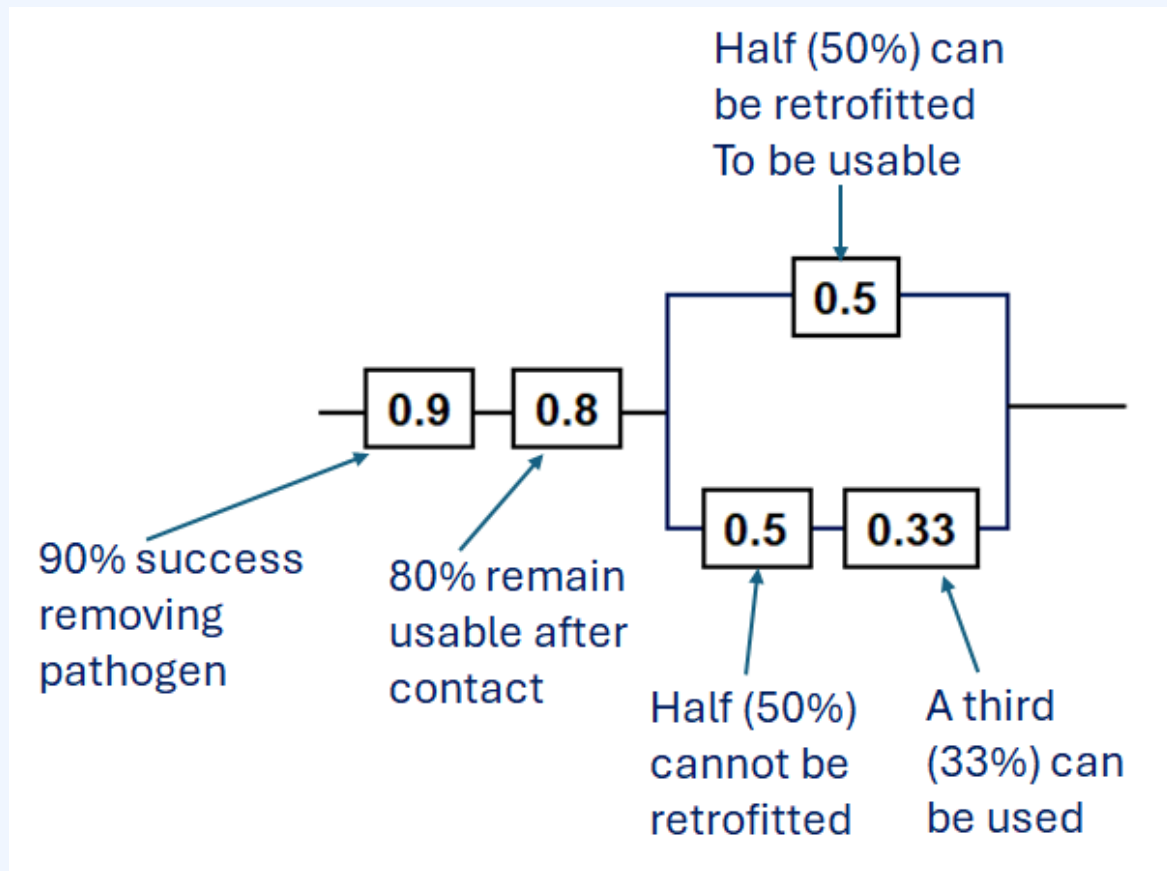


Figure 17.1.7 Reliability Block Diagram

17.1.7 Image Description

A labelled reliability block diagram showing two series components (0.9 and 0.8)

followed by two parallel paths: one with a single block labelled 0.5, and the other with two series blocks labelled 0.5 and 0.33. Blue text annotations explain the meaning of each value: “90% success removing pathogen” beside 0.9, “80% remain usable after contact” beside 0.8, “Half (50%) can be retrofitted to be usable” beside the top 0.5, “Half (50%) cannot be retrofitted” beside the lower 0.5, and “A third (33%) can be used” beside 0.33. The diagram visually represents a system reliability scenario related to usable and non-usable components after processing.

To determine the overall reliability, we analyze the **network of dependencies**:

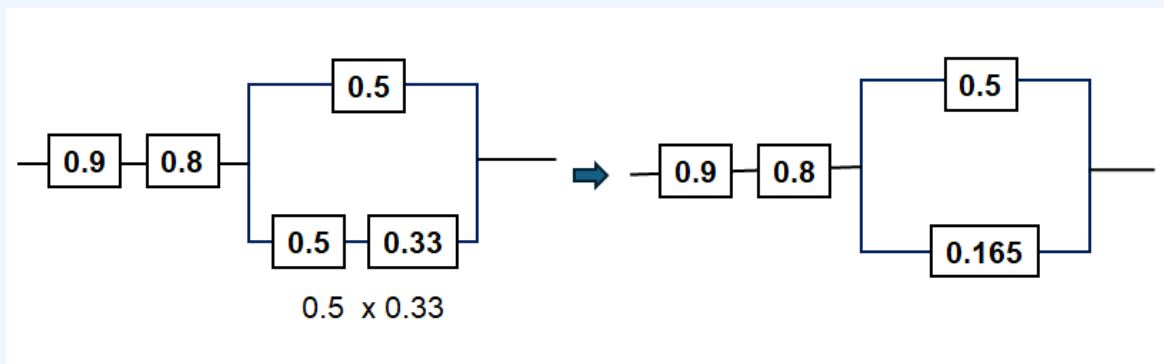


Figure 17.1.8 Reliability Block Diagram

17.1.8 Image Description

Two reliability block diagrams are shown side by side. On the left, two components labelled 0.9 and 0.8 are in series, followed by two parallel branches: one with a single block labelled 0.5 and another with two series blocks labelled 0.5 and 0.33. Below the diagram, the formula “ 0.5×0.33 ” appears. An arrow points to the simplified right-hand diagram, which shows the 0.9 and 0.8 series components followed by parallel blocks labelled 0.5 and 0.165, representing the equivalent system reliability simplification.

As shown below, the yield of the parallel components can be calculated.

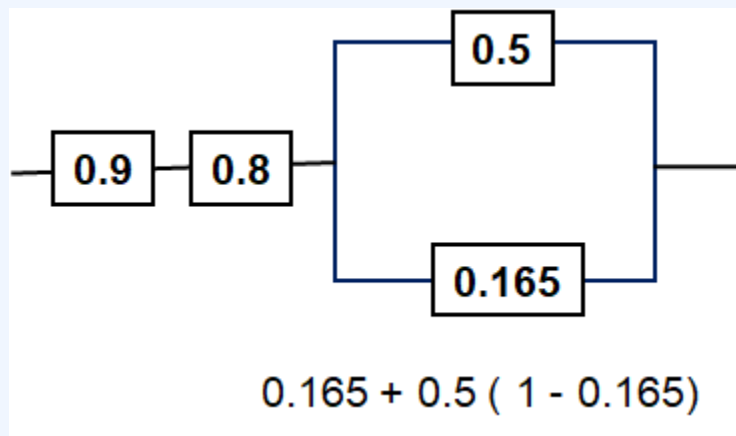


Figure 17.1.9 Reliability Block Diagram

17.1.9 Image Description

A reliability block diagram with two components in series, labelled 0.9 and 0.8, followed by two components in parallel, labelled 0.5 and 0.165. Below, a formula shows: “0.165 + 0.5(1 – 0.165).”

And with that calculation, three serial components exist whose collective yield is easily calculated as shown below.

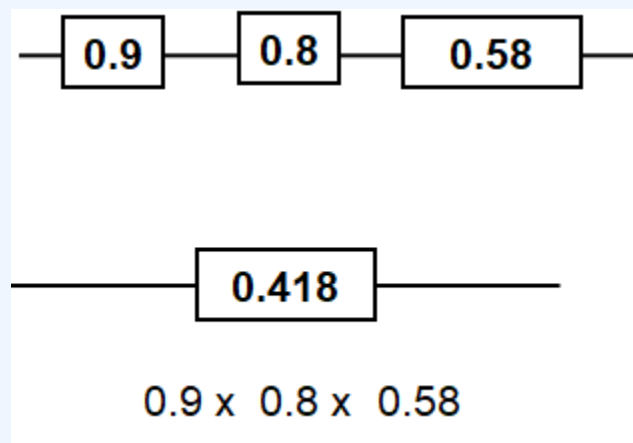


Figure 17.1.10 Reliability Block Diagram

17.1.10 Image Description

A reliability block diagram showing three components connected in series, each

labelled with reliabilities of 0.9, 0.8, and 0.58. Below the diagram, there is a single block labelled 0.418, with a formula underneath: “ $0.9 \times 0.8 \times 0.58$.”

Therefore, based on the above-mentioned interdependencies, this filter has a success probability of 41.8% to remove the pathogens in an hour of peak flow (Rahnamay-Naeini, 2016).

“[Basic Terms of Reliability](#)” & “[Reliability of Systems](#)” from [Concise Reliability for Engineers](#) by Jaroslav Mencik is licensed under a [Creative Commons Attribution 3.0 License](#),

17.2 RELIABILITY METRICS



As introduced earlier in this chapter, **reliability** is a measure of how consistently a system, product, or service performs its intended function without failure over a specified time period. To quantify this, several key **reliability metrics** are used. These metrics help evaluate performance, identify areas for improvement, and guide design and maintenance decisions.

Failure Rate Percentage(%)

This basic metric expresses the proportion of failed units relative to the total number tested, typically over a defined time period. It is calculated using the formula:

$$\text{FR}\% = \frac{\text{Failed units}}{\text{Total units}} \times 100$$

Example:

Magtis Electric tested 1,000 light bulbs overnight. If 20 bulbs failed, the failure rate is:

$$\text{FR}\% = \frac{20}{1000} \times 100 = 2\%$$

Failure Rate (λ)

The **failure rate**, denoted by λ , represents the rate at which a product or system fails over time. It applies to both repairable and non-repairable items and is typically expressed as failures per unit time.

$$\text{Failure Rate } (\lambda) = \frac{\text{Number of Failures}}{\text{Operating Time (Cycles)}} = \text{Failure in time unit (per hour)}$$

Example:

Magtis Electric tested 30 hair dryers designed to operate continuously for 1,000 hours. If 10 units failed at various times, the failure rate can be calculated using the total operating time and the number of failures.

Tested Units	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
Failed after	500	550	600	450	780	680	350	410	720	370

Based on the above failure data, the failure rate of this product is:

$$\text{Failure Rate } (\lambda) = \frac{10}{(500 + 550 + 600 + 450 + 780 + 680 + 350 + 410 + 720 + 370) + 20(1000)} = 0.000394$$

The above number does not reveal a meaningful measure of the reliability of this product for its user. The users buy this product because they expect the product to last for 1000 hours if used continuously. Using the failure rate, however, a more meaningful reliability measure can be obtained in terms of MTTF and MTBF. These two measures are reviewed in more detail.

Note: The raw failure rate alone may not provide meaningful insight for users. More informative metrics, such as MTTF and MTBF, are derived from it.

Mean Time to Failure (MTTF)

MTTF is used for **non-repairable items** (e.g., batteries, light bulbs). It represents the average time until failure and is calculated as:

$$\text{MTTF} = \theta = \frac{\text{Operating Time (Cycles)}}{\text{Number of Failures}}$$

This metric helps estimate how long a product is expected to function before failing.

Mean Time Between Failures (MTBF)

MTBF applies to **repairable systems** (e.g., refrigerators, industrial machines). It measures the average time between successive failures, including the time taken for fault diagnosis and repair.

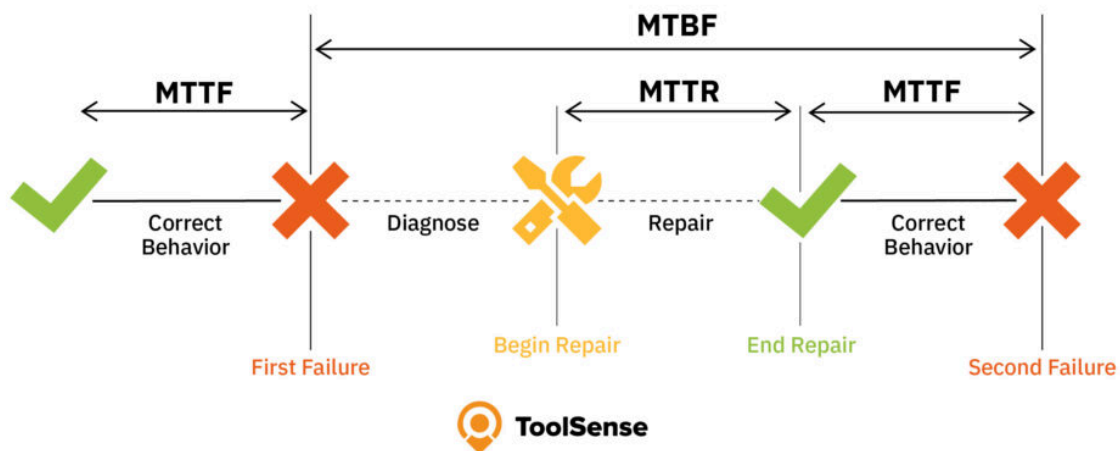


Figure 17.2.1 MTTF and MTBF [click to enlarge] (ToolSense, n.d.)

Image Description

This image illustrates a timeline of a system's operation and maintenance cycle, highlighting different stages of performance and repair. The timeline is divided into several sections, marked by symbols and labels:

- Correct Behaviour – The system is operating normally.
- First Failure – The point at which the system fails.
- Diagnose – The phase where the issue is identified.
- Begin Repair – The start of the repair process.
- Repair – The phase of fixing the issue.
- End Repair – Repair is completed, and normal operation resumes.
- Correct Behaviour – The system is back to normal operation.
- Second Failure – The next failure point of the system.

Additional labels and arrows indicate time intervals:

- MTTF (Mean Time to Failure) – The average time between the start of normal operation and a failure.
- MTBF (Mean Time Between Failures) – The average time between two consecutive failures.
- MTTR (Mean Time to Repair) – The time taken to diagnose and repair the system after a failure.

The formula is:

$$\text{MTBF} = \theta = \frac{\text{Operating Time (Cycles)}}{\text{Number of Failures}}$$

Relationship Between MTBF/MTTF and Failure Rate

Both MTTF and MTBF are statistical predictions based on historical data. They do not guarantee failure-free operation but provide useful estimates of expected performance. Importantly, they are **inversely related** to the failure rate:

$$\text{MTTF \& MTBF} = \theta = \frac{\text{Operating Time (Cycles)}}{\text{Number of Failures}}$$

$$\text{FR} = \lambda = \frac{\text{Number of Failures}}{\text{Operating Time (Cycles)}}$$

OR

$$\text{MTTF \& MTBF} = \theta = \frac{1}{\lambda}$$

Example Revisited: Hair Dryer Reliability

If the failure rate $\lambda = 0.000394$, then:

$$\text{MTBF} = \theta = \frac{1}{0.000394} = 2538 \text{ hours of failure}$$

This means the average time between failures for the hair dryer is approximately **2,538 hours**. If customer expectations exceed this value, the manufacturer may need to revise the design. If expectations are lower, the product has exceeded performance standards (Haney, 2021).

For further explanation, refer to this instructional video:

Video: “[What is MTBF and How to Calculate | Mean Time Between Failure](#)” by [LeanVlog](#) [1:53] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

17.3 MAINTENANCE

All products, systems, and machinery are susceptible to failure over time. To prevent or delay such failures, *maintenance* plays a critical role in ensuring continued functionality and operational reliability.

Maintenance encompasses all activities aimed at keeping equipment and systems in working order. It includes both **preventive measures**, designed to avoid failures before they occur, and **reactive measures**, which address issues after a failure has taken place. The overarching goal is to sustain performance, extend asset life, and minimize downtime.

Effective maintenance management depends on a firm's ability to:

Establish and foster a maintenance culture.

Promoting awareness, accountability, and proactive behaviour across all levels of the organization

Adopt an appropriate maintenance strategy.

Selecting the right mix of preventive, predictive, and corrective approaches based on asset criticality and operational context.

Align maintenance practices with reliability goals.

Ensuring that maintenance activities directly support the reliability targets of systems and equipment.

These foundational concepts will be explored in the following sections to provide a comprehensive understanding of maintenance as a strategic function within operations management. These concepts will be briefly examined in the following sections.

Maintenance Culture

A strong maintenance culture is foundational to achieving high levels of equipment reliability and operational excellence. It extends beyond the maintenance department, requiring commitment from every

employee, from machine operators to senior management. In such a culture, maintenance is not viewed as a reactive task but as a shared responsibility embedded in daily operations.

This collective mindset fosters proactive behaviour, where potential issues are anticipated, communicated early, and resolved collaboratively. Employees understand their roles in maintaining equipment health, performing basic preventive maintenance tasks, and promptly reporting any abnormalities.

A well-established maintenance culture lays the groundwork for Total Productive Maintenance (TPM), which integrates principles of Total Quality Management (TQM) with a strategic, organization-wide approach to maintenance.

Key Elements of a Maintenance Culture

Employees can play essential roles in supporting maintenance management through the following behaviours:

- *Ownership of Equipment:* Operators are responsible for conducting routine inspections, cleaning, and identifying early signs of wear or malfunction. This sense of ownership increases accountability and responsiveness.
- *Prompt Communication:* Staff are encouraged to report issues immediately, helping to minimize downtime and prevent minor issues from escalating into major failures.
- *Collaboration Across Functions:* Cross-functional communication between production and maintenance teams ensures that operational insights are shared, enabling more effective troubleshooting and planning.
- *Continuous Learning and Training:* All employees receive training in basic maintenance practices, safety protocols, and improvement techniques. This reinforces a culture of vigilance and continuous improvement.

By breaking down silos between departments, a strong maintenance culture promotes a holistic approach to asset management, aligning maintenance with broader organizational goals.

Organizational Benefits of a Strong Maintenance Culture

1-Enhanced Capacity Utilization

Reliable equipment reduces unplanned downtime, allowing firms to operate closer to full capacity and meet production targets efficiently.

2-Improved Product Quality

Well-maintained machines produce more consistent outputs, reducing defects, rework, and customer complaints.

3-Strengthened Brand Reputation

Consistent quality and reliability enhance customer trust and satisfaction, contributing to a stronger market position and competitive advantage.

4-Reduced Process Variability

Stable equipment performance minimizes fluctuations in output, making it easier to meet specifications and improve process control.

5-Support for Continuous Improvement

Maintenance culture aligns with frameworks like *TPM* and *Lean Manufacturing*, encouraging regular evaluation of practices, employee-driven problem-solving, and sustained performance improvements (Alsayouf, 2007).

17.4 MAINTENANCE STRATEGIES

Maintenance strategies form the backbone of effective asset management, directly influencing operational efficiency, equipment reliability, and cost control. Selecting the appropriate mix of strategies enables organizations to extend asset life, reduce unplanned downtime, and optimize resource utilization.

This section outlines the primary maintenance strategies commonly used across industries (Fiix Software, 2023).

1. Reactive Maintenance (Run-to-Failure / Corrective Maintenance)

Reactive maintenance involves taking corrective action only after equipment has failed or a defect has been detected. Often referred to as **run-to-failure**, this approach is typically reserved for non-critical assets where failure does not significantly impact safety, operations, or costs.

Examples: Light bulbs, inexpensive motors, or non-essential tools.

Key Characteristics:

- Minimal planning or upfront investment.
- Repairs or replacements occur only after failure.

Advantages	Disadvantages
Simple to implement with low administrative burden.	High unpredictability and risk of costly emergency repairs.
Lower short-term costs due to maintenance being performed only when needed.	Increased downtime and potential for secondary damage.
	Unsuitable for critical systems due to safety and operational risks.

2. Preventive Maintenance (PM)

Preventive maintenance involves performing scheduled inspections, servicing, and part replacements at predetermined intervals—either time-based (e.g., monthly) or usage-based (e.g., after 1,000 operating hours). The goal is to prevent failures before they occur.

This strategy is ideal for equipment with predictable failure patterns or those subject to regulatory compliance (e.g., elevators, fire alarms).

Key Characteristics:

- Maintenance is performed regardless of the current equipment condition.
- Focuses on early detection of wear and tear.

Advantages	Disadvantages
Reduces breakdowns and unplanned downtime.	May result in unnecessary maintenance or over-servicing.
Increases asset reliability, efficiency, and lifespan.	Requires careful scheduling and documentation.
Enhances safety by addressing issues before escalation.	Does not eliminate all failures.

3. Predictive Maintenance (PdM)

Predictive maintenance uses real-time monitoring, data analytics, and diagnostic tools (e.g., vibration analysis, thermal imaging, sensor data) to predict when equipment is likely to fail. Maintenance is then performed only when needed, based on actual asset condition.

This strategy is best suited for high-value or complex assets where failures are costly or disruptive (e.g., turbines, production lines).

Key Characteristics:

- Condition-based rather than schedule-based.
- Requires investment in monitoring technologies and skilled personnel.

Advantages	Disadvantages
Minimizes downtime and avoids unnecessary maintenance.	High initial cost for sensors, software, and analytics.
Maximizes asset lifespan and operational efficiency.	Requires skilled staff to interpret data accurately.
Enables precise planning for parts and labour.	It may not be feasible for all asset types.

Condition-Based Maintenance (CBM)

A specialized form of predictive maintenance, **CBM** triggers maintenance actions only when specific measured conditions (e.g., temperature, vibration, pressure) exceed predefined thresholds. It is highly responsive and tailored to the real-time state of the asset.

Example: A pump is serviced only when vibration levels exceed safe limits, as detected by sensors.

Strategic Integration

In practice, organizations often adopt a hybrid approach, combining multiple strategies based on asset criticality, cost, and operational context. For example:

- Reactive maintenance for low-risk, low-cost assets.
- Preventive maintenance for moderately critical systems.
- Predictive/condition-based maintenance for high-value or safety-critical equipment.

The following video gives a comparative review of the above maintenance strategies.

Video: “[3 Maintenance Strategies: Which Works Best?](#)” by [Asset Insights](#) [3:42] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

Aligning Maintenance with Reliability

As established throughout this chapter, maintenance is a key enabler of reliability. The effectiveness of maintenance activities depends on how well they align with the principles of reliability engineering—namely, minimizing failure, maximizing uptime, and optimizing asset performance over time.

While various maintenance strategies offer different levels of success, two advanced approaches—Reliability-Centred Maintenance (RCM) and Risk-Based Maintenance (RBM)—are particularly effective in aligning maintenance with reliability goals.

1. Reliability-Centred Maintenance (RCM)

RCM is a comprehensive strategy that integrates multiple maintenance approaches to optimize asset performance based on criticality, failure modes, and operational context. It uses Failure Mode and Effects Analysis (FMEA) to identify the most appropriate maintenance method—reactive, preventive, or predictive—for each asset.

RCM is especially valuable in industries with diverse and mission-critical assets, such as utilities, pharmaceuticals, and food processing, where reliability is non-negotiable.

Key Features:

- Tailors maintenance to asset-specific risks and functions.
- Focuses on maximizing reliability while controlling costs.
- Encourages continuous improvement through feedback loops.

Advantages	Disadvantages
Highly customized, improving asset availability and safety.	Requires detailed analysis and data collection.
Reduces unnecessary maintenance and optimizes resource use.	Higher upfront investment in training and system design.
Supports long-term reliability and cost-efficiency.	Complex to implement, especially in large organizations.

The following video provides a brief review of reliability-centred maintenance

Video: “[Chapter 1 – Introduction to Reliability Centered Maintenance](#)” by [Get Insight](#) [6:38] is licensed under the [Standard YouTube License](#). *Transcript and closed captions available on YouTube.*

2. Risk-Based Maintenance (RBM)

RBM prioritizes maintenance activities based on the **risk** associated with asset failure, considering both the likelihood and consequences of failure. Assets are ranked using risk assessment tools (e.g., risk matrices), and maintenance schedules are adjusted accordingly.

This strategy is particularly effective in safety-critical or environmentally sensitive environments, such as nuclear power plants, chemical processing, or aviation.

Key Features:

- Focuses resources on high-risk assets.
- Enhances safety, compliance, and operational resilience.
- Requires ongoing reassessment as conditions evolve.

Advantages	Disadvantages
Improves risk management by targeting critical assets.	Depends on accurate risk and consequence analysis.
Enhances safety and regulatory compliance.	Requires continuous monitoring and reassessment.
Optimizes resource allocation.	May overlook low-risk assets that still impact performance.

Comparison of Maintenance Strategies

Strategy	Description	Key Benefits	Best Used For
Reactive / Corrective	Fix after failure	Simple, low upfront cost	Non-critical, low-risk assets
Preventive	Scheduled routine maintenance	Reduces failures, predictable costs	Assets with predictable wear
Predictive	Data-driven, real-time monitoring	Optimized timing, minimized downtime	High-value, critical equipment
Condition-Based	Based on asset condition thresholds	Just-in-time, efficient	Assets with variable operating conditions
Reliability-Centered	Combined, optimized methods	Risk-based, resource-efficient	Complex, critical facilities
Risk-Based	Prioritized by risk impact	Focuses on critical assets	Risk-sensitive operations

17.5 COST OF RELIABILITY AND MAINTENANCE

Improving reliability through maintenance inevitably incurs costs. According to fundamental economic principles, these costs must be weighed against the benefits of increased reliability, such as reduced breakdowns, lower repair expenses, and improved operational continuity.

The cost dynamics vary depending on the maintenance strategy employed:

- *Reactive maintenance* typically results in low prevention costs but high repair costs, as failures occur more frequently and often unexpectedly.
- *Preventive maintenance*, on the other hand, involves higher upfront prevention costs but significantly reduces repair costs by minimizing the frequency and severity of failures.

The goal is to find an optimal balance between these two cost components to minimize total maintenance cost while achieving desired reliability levels. As illustrated in Figure 17.5.1, this balance is achieved through intelligent maintenance, where the total cost is minimized at the point where repair and prevention costs intersect.

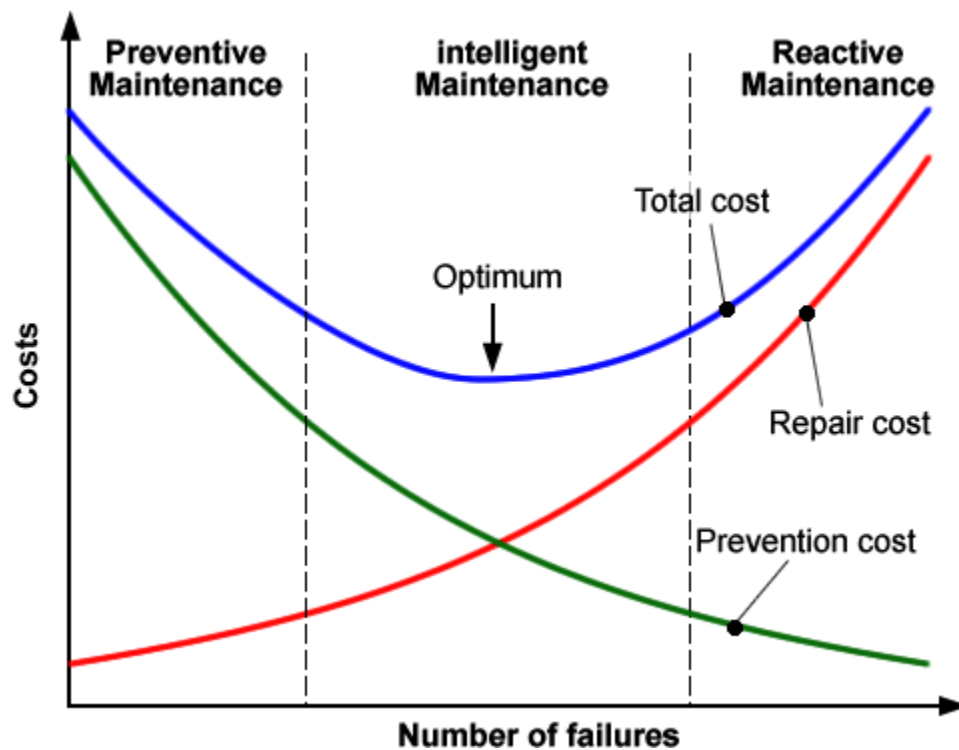


Figure 17.5.1: Cost associated with traditional maintenance strategies. [Figure](#) by Tchakoua, P., Wamkeue, R., Ouhrouche, M., Slaoui-Hasnaoui, F., Tameghe, T. A., & Ekemb, G., [CC BY 3.0](#)

Key Considerations in Cost Balancing

Two important points must be considered when evaluating maintenance cost strategies:

1. *Variability in Cost Curves:* Different preventive measures yield varying levels of failure reduction at different costs. This results in multiple prevention and repair cost curves, each with its own rate of change ($\Delta\text{Cost} / \Delta\text{Breakdown}$). Consequently, the balanced maintenance zone may shift, producing multiple total cost curves and different optimal points. For simplicity, the curves shown in Figure 17.5.1 represent average cost behaviour.
2. *Accounting vs. Opportunity Costs:* Traditional cost analysis often focuses on direct (accounting) costs—such as labour, parts, and downtime. However, opportunity costs must also be taken into account. These include:
 - Lost production and delivery delays
 - Customer dissatisfaction and potential loss of future sales
 - Reputational damage
 - Safety risks and reduced employee morale

Full-Cost Approach to Maintenance Decision-Making

To determine the appropriate level of maintenance investment, organizations should adopt a full-cost approach, incorporating both direct and opportunity costs. This requires access to historical data on:

- Breakdown frequencies and probabilities
- Repair durations and costs
- Maintenance expenditures

The following example illustrates how this approach can guide decision-making between reactive and preventive maintenance strategies.



Example: Maintenance Decision for a Courier Fleet

Shahab operates a courier service in London using a fleet of 10 trucks. Frequent braking and harsh road conditions cause brake callipers to seize, requiring costly repairs. He has two options:

Option 1: Reactive Maintenance

- Average brake repair cost: \$2,000
- Downtime rental cost: \$250/day
- Repair time: 0.5 days

Option 2: Preventive Maintenance

- Monthly contract with Bobbie (retired mechanic): \$10,000
- Prevents 75% of breakdowns

Historical Data (24 months)

Brake Breakdowns	Months Observed	Frequency
0	4	0.165
1	10	0.42
2	6	0.25
3	4	0.165

Solution

Step 1: Determining the frequency and expected number of breakdowns based on past data

Number of brake breakdowns and Repair	Number of months during which the breakdown/repair happened	Frequency of breakdowns
0	4	$4/24 = 0.165$
1	10	$10/24 = 0.42$
2	6	$6/24 = 0.25$
3	4	$4/24 = 0.165$

Step 2: Determining the expected number of breakdowns based on past data

Expected monthly # = $\sum (\# \text{ of months}) (\text{associated Frequency})$

$$= (4) (0.165) + (10) (0.42) + (6) (0.25) + (4) (0.165)$$

$$= 0.66 + 4.2 + 1.5 + 0.66$$

$$= 7.02 \text{ breakdowns/month}$$

Step 3: Determining the expected breakdown repair cost based on past data

Expected BD cost = (Expected # of months) (breakdown cost + rental cost)

$$= (7.02) (\$2,000 + 250)$$

$$= \$15,795 \text{ per month}$$

Step 4: Determining the expected preventive maintenance cost based on past data

Expected Preventive Cost = Contract cost + expected breakdown cost with contract

$$= \$10,000 + (0.25) (\$2000) (7.02)$$

$$= \$13,510 \text{ per month}$$

Decision: Preventive Maintenance based on cost, Reactive Maintenance (\$15,795) or Preventive Maintenance (\$13,510)

17.6 CHAPTER SUMMARY & REVIEW



Summary

Reliability is the probability that a component or system performs its intended function over a specified time and conditions. System reliability depends on configuration: in series, overall reliability decreases as more components are added because any single failure stops the system; in parallel, redundancy enhances reliability because a backup can take over the load. Real systems also exhibit interdependence; failures can cascade, so designers often combine redundancy and recovery mechanisms to mitigate this risk. Reliability is quantified with metrics such as failure rate (λ), mean time to failure (MTTF) for non-repairable items, and mean time between failures (MTBF) for repairable systems, which guide expectations, design choices, and service plans.

Maintenance is the operational counterpart to reliability. A strong maintenance culture, characterized by shared ownership, prompt communication, cross-functional collaboration, and continuous training, enhances capacity utilization, quality, safety, and reputation. Organizations mix strategies by asset criticality: reactive (run-to-failure) for low-risk items; preventive (time/usage-based) for predictable wear; and predictive/condition-based for high-value assets, with advanced frameworks like Reliability-Centred Maintenance (RCM) and Risk-Based Maintenance (RBM) aligning actions to failure modes and consequences. Economically, the goal is to balance prevention and repair costs while accounting for opportunity costs. Using historical breakdown data and a full-cost lens helps select the most cost-effective policy and schedule work that maximizes uptime and performance

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: *Please take the chapter content in this document attached and summarize the key concepts into no more than two paragraphs. Reviewed by authors.*



Review Questions

1. Define system reliability and explain how it changes in a series versus parallel configuration.
2. Discuss the role of redundancy in improving system reliability, providing an example.
3. Explain reactive maintenance and its main disadvantages.
4. Summarize how preventive maintenance differs from predictive and condition-based maintenance.
5. Identify and describe one hidden cost of equipment breakdowns that is not directly monetary.
6. Compare and contrast reliability-centred maintenance with risk-based maintenance.
7. Why is it important to include opportunity costs in a maintenance cost analysis?
8. Outline the steps you would take to use historical breakdown data for estimating future maintenance needs.
9. Discuss how maintenance strategies might differ between a manufacturing plant and a service organization.
10. In your own words, describe how maintenance activities relate to the overall reliability of an asset.

Calculation Questions

1. Calculate the reliability of a system with components in series: $R_1=0.92$, $R_2=0.85$, $R_3=0.70$.
2. For a 2-unit parallel system where each unit has a reliability of 0.6, compute the overall system reliability.
3. Using the observed breakdown data (0, 1, 2, 3 incidents per month over 24 months), calculate the average number of breakdowns per month.
4. If the average repair cost per breakdown is \$1,500 and there are 8 expected

breakdowns per month, what is the total monthly repair cost?

5. Compare the total expected monthly costs between paying for breakdown repairs (\$2,000 each, average of 6 per month) and hiring a mechanic for preventive maintenance at a rate of \$10,000 per month, assuming preventive maintenance prevents 75% of breakdowns.

OpenAI. (2025). *ChatGPT*. [Large language model]. <https://chat.openai.com/chat>

Prompt: Create ten discussion questions based on the attached chapter document that assess the student's knowledge based on the learning outcomes for the chapter.

Reviewed by authors.

17.7 CASE STUDY: HOLIDAY BASKETS



Case Study: Holiday Baskets

Holiday Baskets is a small seasonal business specializing in the preparation and delivery of nut baskets during the Christmas season. The company was founded by Helen Hemkey, who oversees all aspects of operations, from order intake to final delivery.

The business model is simple: customers place orders for baskets containing four types of nuts (walnuts, cashews, almonds, and peanuts), all of which are kept in stock. Helen receives the orders, picks the required quantities of nuts, and places them into bags along with shipping labels. These are then sent to the basketing workshop, where her four employees, *Dianne, Nancy, Sue, and Mariam*, assemble the final product.

- Dianne works independently at Table 1.
- Nancy and Sue collaborate at Table 2, with Nancy starting the basket and Sue completing it.
- Mariam works independently at Table 3.

Once assembled, the baskets are labelled and placed on the pick-up table for courier delivery.

Concern 1: Quality Assurance

Helen has built a strong reputation for the presentation quality of her baskets, specifically, that the nuts are neatly sectioned and do not mix. She aims to keep

the defect rate below 2%. However, based on recent observations, she estimates that each employee has a 5% probability of producing a disarrayed basket.

Question: *Can Helen maintain her desired quality standard of 98% or higher for the final baskets?*

Analysis:

Let's assume the probability that each basket is correctly assembled is:

$$P_{\text{correct}}=0.95$$

The probability that all three workstations (Dianne, Nancy, Sue, and Mariam) produce a correct basket is:

$$P_{\text{system success}}=0.95 \times 0.95 \times 0.95 = 0.857375$$

However, we must consider the complement—the probability that at least one basket is disarrayed. The probability that all three produce a disarrayed basket is:

$$P_{\text{all fail}}=(1-0.95)^3=0.000125$$

Thus, the probability that at least one basket is correct is:

$$1-P_{\text{all fail}}=1-0.000125=0.999875$$

Yes, Helen can maintain her quality standard. The probability that the baskets are correctly assembled exceeds **99.98%**, which is well above her 98% threshold.

Concern 2: Delivery Reliability

Helen strives for next-day delivery and uses multiple courier companies to increase the likelihood of on-time delivery. Each courier has a 70% probability of delivering on time.

Question: *She wants to know how many independent couriers, each carrying an*

identical set of orders, are needed to achieve at least 99% confidence in next-day delivery.

Analysis:

- $P=0.70$ ($P=0.70$ (probability of success per courier))
- n = number of couriers
- We want:

Pat least one success ≥ 0.99

$$1 - (1 - P)^n \geq 0.99 \Rightarrow (1 - P)^n \leq 0.01$$

$$(1 - 0.70)^n \leq 0.01 \Rightarrow (0.30)^n \leq 0.01$$

- $n=1$: 0.300.30
- $n=2$: 0.090.09
- $n=3$: 0.0270.027
- $n=4$: 0.00810.0081

Helen needs to use at least 4 courier companies, each carrying the same set of orders, to achieve 99% confidence in next-day delivery.

17.8 KEY TERMS



Key Terms

- **Condition-Based Maintenance (CBM)** is a specialized form of predictive maintenance that triggers maintenance actions only when specific measured conditions (e.g., temperature, vibration, pressure) exceed predefined thresholds.
- **Failure rate Percentage (%)** expresses the proportion of failed units relative to the total number tested, typically over a defined time period.
- **Failure Rate** represents the rate at which a product or system fails over time.
- **Maintenance** encompasses all activities aimed at keeping equipment and systems in working order.
- **Mean time between failure (MTBF)** applies to repairable systems and measures the average time between successive failures, including the time taken for fault diagnosis and repair.
- **Mean time to failure (MTTF)** is used for non-repairable items to represent the average time until failure.
- **Predictive maintenance** uses real-time monitoring, data analytics, and diagnostic tools to predict when equipment is likely to fail.
- **Preventive maintenance** involves performing scheduled inspections, servicing, and part replacements at predetermined intervals—either time-based (e.g., monthly) or usage-based (e.g., after 1,000 operating hours).
- **Reactive maintenance** involves taking corrective action only after an equipment failure or a defect has been detected.
- **Redundancy** refers to the inclusion of additional or backup components in a system to enhance its overall reliability.

- **Reliability** is a measure of how consistently a system, product, or service performs its intended function without failure over a specified time period.
- **Reliability-Centred Maintenance (RCM)** is a comprehensive strategy that integrates multiple maintenance approaches to optimize asset performance based on criticality, failure modes, and operational context.
- **Reliability metrics** help evaluate performance, identify areas for improvement, and guide design and maintenance decisions.
- **Risk-Based Maintenance (RBM)** prioritizes maintenance activities based on the risk associated with asset failure, considering both the likelihood and consequences of failure.
- **System** typically comprises multiple subsystems, each made up of individual components.
- **System reliability** refers to the likelihood that an entire system will function without failure over a specified period.

VIDEO TRANSCRIPTS

16.4 Just-In-Time (JIT) Systems

VSM .Value Stream Mapping

Hi everyone, today's video is to learn value stream mapping. There are three objectives.

The first objective is to draw the current state plan.

The second is to identify improvement opportunities.

And the third is to make a future state map.

But how do we do it?

I'll tell you. We will show this by simulating a physical supply chain corresponding to the map on the screen.

Now, let us introduce the supply chain. The supply chain is about producing 2 varieties of these wheels: one is with a green cap, and one is with a yellow cap.

I will be the customer. I will give the order to Amrsha.

I'm the planner and the heart of the company. I take the order, make changes to it, and give it to Aishwarya.

I'm the supplier. I take the order from her, and I send the material to the receiving warehouse. I may also introduce some changes to achieve full load capacity of the truck.

Since I'm the planner, I also give the instruction to the departments of the company.

I'm Rashmi, and I received my order from the planner in the shop. My department procured the material from the receiving warehouse and our job is to stick these wheel caps to the wheels and keep it in the intermediary warehouse.

I'm Sakshi, I'm department two. My work is to attach a screw in the wheel.

I'm Shubhangi, and the operation here is to put the logo on the wheel and put it in the finished goods section. I also get my plan from Amrsha.

Can you see the correspondence between the physical simulation and the map? We've even tried to color code it for you.

Now that we have the process going in place, what else is missing? these details, we need the cycle time and the changeover time of each of these operations. Rashmi what is yours?

I have a cycle time of 10 seconds and a changeover time of one hour.

Sakshi.

My cycle time is 20 seconds and changeover time of two hours.

Shubhangi.

Well, I have to work according to the speed of the bottleneck, so my only work is to put the same drive logo, and that is why I have no changeover and my cycle time is of 10 seconds.

Great, let's fill in the details now.

It is a combination of the information flow and the material flow. The dotted lines indicate the information, and the pink lines indicate the material's flow.

So, what is the biggest advantage of VSM?

Kashyap, it is showing up non valuating activities and valuating activities in proportion to each other, you know the biggest non valuating activity, it is waiting, here is the waiting, that is the WIP contributed by these two.

The next step is to calculate the value adding and nonvalue adding time. Let's start.

My value adding time is 10 seconds, but I have 15 inventory waiting.

So, how does it translate into time?

Each one would take 10 seconds, so 15 into 10, 150 seconds.

OK what about the next operation.

So, my value adding time is 20 seconds, and the inventory waiting is 7. So, total nonvalue adding time will come down to 140.

Alright so 20 seconds while waiting and 140 seconds of nonvalue adding. Great, Shubhangi.

So, my value adding time is just 10 seconds, and my inventory time is one, two, three. 3 into 10, 30 seconds.

So, now what I did was, I told you the time I put it up on the map. The triangle with an 'I' represents the inventory waiting, and this is the time that is waiting for, 4 into 10, 40 seconds for this process.

So, what will you do with this data?

Let me tell you. We will calculate the value adding ratio, where we will calculate the ratio, which is 40 above 370, which gives us 10.8% only.

That means almost 89% of the time is non value adding.

Yes.

Yeah, but it sleeps almost 90% of the time.

The current state map is now ready, it's now ready, it's on the diagram, and to understand it better, it's also physically demonstrated.

This planner, she gave me so many changeovers! Doesn't she realize I have a huge changeover time? I cannot finish this with a given plan, I'll stick to whatever best I can do.

Since I'm the bottleneck of the process, I cannot sit idle, and I have to keep working with whatever I have.

What I get from Sakshi does not meet the plan. So, to utilize the capacity I produce what I get.

All these problem areas are the improvement opportunities which we can work upon. These improvement opportunities are shown by the starburst on the map. But how to work upon them?

Firstly, the planner makes only one plan and interacts only with the last operator. This creates the pull system of material flow.

I'll be the happiest here.

Oh, and also we can add the supermarket and Kanban system here.

But what about the high changeover time?

We can use SMED.

And you can watch a video on SMED of us too on the same channel.

Now, this is our future state map and the change physical simulation. Amrsha will you tell us about it?

Sure, what I do according to this map is I give the order to the third operator. Here is your plan.

Thank you. So now, only I get the plan. So as soon as I start working on the piece, I take the Kanban card and put it in the Kanban order box.

So, now I will start working as per the common receipt. I will pull this much of material from the supermarket and start working on it, and I'll also put this Kanban card to my previous operator.

Based on the Kanban, I can procure the material from the supermarket and start working on it, so using SMED my changeover time has drastically disappeared. I can produce whatever comes to me. Now that I've finished my operation, I take the Kanban card and the material and replenish the supermarket and wait for the next order.

Here, we were able to achieve three things. The first, we could work with very less inventory. The second, is get down the non value adding time. And the third, that we were able to increase the value adding ratio.

I hope you understood by this physical simulation and diagram how to use the tool of value stream.

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VERSION HISTORY

This page provides a record of edits and changes made to this book since its initial publication. Whenever edits or updates are made in the text, we provide a record and description of those changes here. If the change is minor, the version number increases by 0.1. If the edits involve a number of changes, the version number increases to the next full number.

The files posted alongside this book always reflect the most recent version.

Version	Date	Change	Affected Web Page
1.0	October 15, 2025	First publication	N/A